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MODELING ATTACK HELICOPTER OPERATIONS IN THEATER LEVEL SIMULATIONS

by

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This thesis describes an attack helicopter module for the *Joint Warfare Analysis Experimental Prototype (JWAEP)*, a joint theater level, low resolution stochastic simulation developed at the Naval Postgraduate School. The modeling formulations, required data, and assumptions which are required to portray attack helicopter operations in theater level simulations are presented. The focus for the attack module is the representation of attack helicopter units in the conduct of deliberate attacks; however, many of the models described can be applied to general helicopter operations. The formulations are limited to the major events that occur during an attack helicopter deliberate attack and represent initial research to portray attack helicopter operations in JWAEP.

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MODELING ATTACK HELICOPTER OPERATIONS IN THEATER LEVEL SIMULATIONS

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ABSTRACT

This thesis describes an attack helicopter module for the *Joint Warfare Analysis Experimental Prototype (JWAEP)*, a joint theater level, low resolution stochastic simulation developed at the Naval Postgraduate School. The modeling formulations, required data, and assumptions which are required to portray attack helicopter operations in theater level simulations are presented. The focus for the attack module is the representation of attack helicopter units in the conduct of deliberate attacks; however, many of the models described can be applied to general helicopter operations. The formulations are limited to the major events that occur during an attack helicopter deliberate attack and represent initial research to portray attack helicopter operations in JWAEP.

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EXECUTIVE SUMMARY

This thesis describes an attack helicopter module for the *Joint Warfare Analysis Experimental Prototype (JWAEP)*, a joint theater-level, stochastic combat simulation developed at the Naval Postgraduate School. The formulations presented address the specific issues of portraying attack helicopter units conducting deliberate attacks but the general results can be applied to the representation of all helicopter forces.

The representation of helicopter operations in theater level combat simulations is an area that needs improvement. Many low resolution simulations fail to model helicopter forces or model these forces in the same way as fixed-wing aircraft. This thesis represents the initial research in the formulation of models to represent helicopter operations in JWAEP and is an attempt to begin to address the current shortcomings in existing models.

The model formulations presented are based on U.S. Army Aviation doctrine and tactics but also allow the portrayal of helicopter forces that are employed differently. The scope of the thesis is limited to the representation of the basic attack helicopter unit (the attack helicopter battalion), helicopter movement in the user defined network, and the major events that take place during the conduct of a deliberate attack mission. The events described include the selection of optimal ingress and egress flight paths to and from the target area, mission force size determination, maintenance attrition, en route attrition, objective area attrition, and the mission planning cycle and logistical considerations.

A demonstration of model results is shown for the most important areas, the selection of the optimal flight path based on distance and enemy air defense threat, and the adjudication of objective area attrition. All other formulations are accompanied by specific numerical examples to illustrate how the models are applied. Face validity is addressed with the numerical examples and demonstrated results presented but further testing needs to be completed before the module is validated. The module can only be verified when it is coded and incorporated into the JWAEP Model, but initial results indicate the topic is worthy of further research.

I. INTRODUCTION

A. OVERVIEW

The purpose of this thesis is to describe an attack helicopter module for the *Joint Warfare Analysis Experimental Prototype (JWAEP)*, a joint theater-level, aggregated, low resolution simulation developed at the Naval Postgraduate School (NPS). Army aviation is not currently represented in the simulation and the source code requires modifications and additions to accurately portray helicopter operations. The module described in this thesis addresses the modeling of attack helicopter units conducting deliberate attacks but the general results can be applied to the representation of all helicopter forces.

The attack helicopter module is based on current U.S. Army aviation doctrine for attack helicopter operations but will have the flexibility to portray attack helicopter forces which are used and employed in different ways. The module allows for the portrayal of "Red" attack helicopter forces as well as "Blue" forces and is capable of reflecting future doctrinal changes as tactics are refined and updated and attack helicopter technology evolves. The doctrinal foundations of attack helicopter operations are discussed in Chapter II. Specific modeling formulations are addressed in Chapter III in addition to the required supporting data that allow for the representation of attack helicopter operations in the simulation. Major areas described include unit representation, unit movement, air route selection, attrition adjudication, logistics, and mission cycles. Modeling formulations are demonstrated in Chapter IV to include a discussion of results. Chapter V is the conclusion with implementation recommendations and a discussion of areas for further study.

B. BACKGROUND

The ***Joint Warfare Analysis Experimental Prototype (JWAEP)*** is an interactive, two-sided, theater level combat model based on an arc-node representation of ground, air and littoral combat. It can be run in an interactive gaming mode or a closed-form stochastic analysis mode. The level of detail used in JWAEP is appropriate to represent battalion to brigade sized maneuver units, flight groups, and major combatant vessels. JWAEP is a

software prototype developed by the Naval Postgraduate School for research and experimentation in command, control, communications, and intelligence (C^3I) centered approaches to modeling theater-level combat.

Ground warfare is executed upon the arc-node representation of the key terrain, objectives, defensive points and maneuver corridors. Units have the ability to move through the network according to appropriate movement rates and terrain restrictions that are based on the size and maneuver capabilities of each unit. Attrition is assessed through the COSAGE/ATCAL process developed at the U.S. Army Concepts Analysis Agency.*

Air warfare is executed on a separate air grid. The air space within a theater of operations is divided into a user-defined grid, the air grid. Each grid square represents the volume of air from the ground up within the geographic area enclosed by the square. Air-to-air engagements are fought when aircraft encounter each other in a grid square; surface to air and air to surface engagements are fought between flights within an air grid and any ground targets or weapon systems on the terrain underlying the grid. The air grid is represented in the model as a node with direct connectivity to the eight adjacent nodes. Given the air structure, aircraft can choose a "least cost" path through the network to move to an engagement/target area and return. The air-to-air and air-to-surface engagements are adjudicated using the attrition mechanisms in the Air Forces Studies and Analysis Activity's THUNDER model. Surface-to-air engagements are adjudicated using a high resolution algorithm developed at NPS based on THUNDER algorithms.

The littoral warfare module is currently under development. (Youngren and Lovell, 1996)

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* *COSAGE (Combat Sample Generator):* A stochastic division level model used to generate engagement input data for use in ATCAL. The input data is generated based on a specific area of operations and opposing forces. *ATCAL (An Attrition Model Using Calibrated Parameters)*: An attrition model in which calculations are made using high resolution results - results of a simulation resolved down to the interactions between individual weapons. It provides a loss-by-cause table (killer victim scoreboard), allocation of fire among all shooter and target types, expenditures of ammunition, and the relative importance of all weapons. [US Army Concepts Analysis Agency, CAA-TP-83-3, August 1983]

C. THE PROBLEM

The current version of JWAEP, Version 2.0, does not explicitly model Army aviation helicopter forces and the model structure does not allow for the realistic representation of attack helicopter forces and their employment in the deep, close, and rear battle areas. Attack helicopters are only listed as separate entities in the equipment lists of the major ground units which are division level and higher. The model does not allow for the formation or employment of helicopter units capable of independent movement. Attack helicopters are represented as additional weapon systems that contribute to the combat effectiveness of the parent ground unit. That is, they are combat multipliers that contribute to the close fight.

Deep operations conducted by organic ground maneuver forces have partial representation. The *deep attack* can be conducted by weapons such as long range artillery or attack helicopters but the simulation only portrays artillery. The traditional definition of a deep attack or deep strike implies an attack that is conducted across the front line of troops, deep into enemy territory, and normally beyond the range of friendly ground force direct fire support. The term "deep" for the purposes of this thesis will be used to define a strike against any enemy force that is not currently engaged by friendly ground forces.

There is no representation of helicopter maneuver. Helicopter forces plan for and maneuver on appropriate avenues of approach like any ground unit. The added dimension of flight increases their speed, mobility and vulnerability. Attack helicopter units must be able to maneuver as independent units to conduct doctrinal attack operations.

D. ATTACK HELICOPTER MISSION SCENARIO

A scenario will be used throughout the thesis to demonstrate how the modeling techniques discussed can be applied to a typical attack helicopter mission. This section will outline a mission, "Blue" and "Red" forces, and a tactical situation that will form the basis for all examples used to explain specific modeling techniques. This scenario is based on Department of the Army FM 1-112, *Tactics, Techniques, and Procedures for the Attack Helicopter Battalion*, 1991.

1. Concept of the Operation

The Attack Helicopter Battalion (ATKHB) is part of a "Blue" corps aviation brigade. Corps offensive operations begin at D-Day. The corps electronic warfare priority will shift on D+3 to support suppression of enemy air defenses (SEAD) for corps deep attacks against 2nd echelon forces. The attack helicopter regiment has been given the mission to conduct deep attacks to destroy the "Red Force" 2nd echelon tank division, the 22nd Guards Tank Division, at D+3 or D+4. Attack helicopter forces are typically used in deep attacks against follow-on, high-payoff targets that are critical to the corps commander's campaign plan. *Deep attacks* are directed against enemy forces that are not currently engaged but could influence division or corps close operations within the next 24 to 72 hours (FM1-112, 1991, p. 3-34).

2. The ATKHB Mission

The 1-24 ATKHB will conduct a deliberate deep attack to destroy the 22nd TD Independent Tank Regiment (22nd ITR) in Engagement Area Kill (EA Kill) at D+3. (ATKHBs require at least 24-48 hours to plan a deep attack mission.)

3. The Blue ATKHB

The size and organizational structure of an attack helicopter battalion can vary depending on the level at which it exists, the type of attack aircraft assigned, or the missions it will perform. The ATKHB depicted in Table 1.1 represents a typical corps or division heavy attack battalion based on the current Army Aviation Restructure Initiative.

ATKHB Attack Companies	*AIRCRAFT*	*MAX ANTI-TANK GUIDED MISSILES*
A Company	8 AH-64	128 Hellfire
B Company	8 AH-64	128 Hellfire
C Company	8 AH-64	128 Hellfire

Table 1.1 *ATKHB Combat Force.*

4. The Red Force

The 22nd ITR has a tank heavy force with a total of 150 combat vehicles and is depicted in Table 1.2.

VEHICLES	*NUMBER*
Tanks	130 T80
1 Section Rgmt ADA	2 ZSU, 2 SA13
1 Section MRD ADA	2 SA6 TEL, 1 Radar
Mechanized Vehicles	14 BMP2

Table 1.2 *22nd ITR Combat Force.*

II. ARMY AVIATION

A. ROLE OF ARMY AVIATION

Army aviation (helicopter) forces have the flexibility, versatility, and capability to perform as maneuver, combat support, and combat service support forces. Army aviation essential tasks include: supporting the force commander's battle plan, supporting forces in contact, synchronizing force operations, and sustaining force operations (FM1-100, 1989, p. 1-7). Army aviation's role as a maneuver force conducting attack helicopter operations is the focus of this thesis.

Combat aviation maneuver forces, which are usually brigade sized, exist within three major combat unit organizations: Theater or Echelons Above Corps (EAC), Corps, and Division. Each aviation brigade normally has subordinate attack helicopter battalions which are capable of independent mission planning and execution. Attack helicopter units are used in close, deep, and rear operations but their allocation and use differ depending on the level of their parent ground maneuver headquarters. The EAC, corps, and division ground force commander's intent, operational or tactical objectives, and priority mission support requirements will dictate how their respective attack helicopter units are used (FM1-100, 1989, p. 1-12).

There are normally different priorities and operational/tactical objectives at each level of command that govern how, when, and where attack helicopters are deployed. EAC level forces have a strategic-operational perspective of the battlefield and their aviation forces are tailored for the specific theater. If an EAC aviation brigade has a subordinate attack helicopter battalion, it is normally used to support corps and division operations. The majority of attack helicopter battalions or regiments are located in corps level commands where the focus is operational and tactical. The primary missions for corps attack helicopter battalions include counterattacking enemy penetrations of regimental size and conducting deep attacks to destroy enemy second-echelon formations before they can influence the close fight. The focus at the division level is tactical and division attack helicopter battalions are primarily used to support close operations. (FM1-100, 1989)

B. AVIATION EMPLOYMENT PRINCIPLES

Army aviation forces are modeled after maneuver ground force elements, not Close Air Support squadrons.* Therefore, the doctrinal employment principles for Army aviation units are similar to those of conventional ground forces. Aviation employment guidelines outlined in Department of the Army FM1-100, 1989, include:

- *Fight as an integral part of the combined arms team*
- *Exploit the capabilities of other services*
- *Capitalize on intelligence-gathering services*
- *Suppress enemy weapons and acquisition means*
- *Use terrain for survivability*
- *Displace forward elements frequently*
- *Exploit firepower*
- *Mass forces*
- *Exploit mobility*
- *Maintain flexibility*
- *Exploit surprise*
- *Exercise staying power.*

Command and control of Army aviation assets always stays with maneuver force commanders. Aviation units are placed in one of three command relationships: assigned, attached, or operational control (OPCON). The *assigned* relationship refers to a relatively permanent condition. Aviation battalions and companies are normally assigned to an aviation brigade. The *attached* relationship is usually for a short duration and is temporary in nature. A prime example of this is the attachment of a corps attack helicopter battalion to a division aviation brigade to support an offensive initiative. The *OPCON* relationship is also temporary in nature and is usually used when aviation maneuver forces are employed with or by members of the combined arms team. An attack helicopter battalion, for example, can be placed under the OPCON of a ground maneuver brigade or higher-level commander to support a specific mission. Aviation forces are normally not placed under OPCON below brigade level. (FM1-100, p. 2-2)

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* This is true for U.S. Army Aviation Forces but may not apply to other helicopter forces. The Soviet employment of MI-8 and MI-24 attack helicopters for close air support during the Soviet-Afghan War provides a prime counter example. It is notable, however, that Soviet attack helicopter use and tactics changed during the course of the war in response to refined and changing tactics of the Mujahideen. [Baumann, Robert F., *The Soviet-Afghan War, 1979-1989*, from Combat Studies Reading Book, December, 1991, pp. 395-435, CGSOC M/S 621/4 Readings Book, U.S. Army Command and General Staff College, Fort Leavenworth, Kansas]

C. THE ATTACK HELICOPTER BATTALION

The attack helicopter battalion (ATKHB) is the basic unit for attack helicopter forces. The ATKHB is a combat maneuver unit which is employed to conduct supporting attacks to aid, protect, and complement other maneuver forces. The ATKHB allows the force commander to mass combat power rapidly at the decisive time and place to influence the outcome of a battle.

The ATKHB fights as part of a combined arms team, coordinating its attacks with other maneuver, combat support, combat service support, and joint and combined forces, to overwhelm and surprise the enemy at the point of attack. Attacks may be conducted to support close operations or the "deep" fight, but are always synchronized with the ground force scheme of maneuver. (FM1-112, 1991, p. 1-2)

1. The Mission

The mission of the ATKHB is to destroy massed enemy mechanized forces and other forces using aerial firepower, mobility, and shock effect. The attack battalion is also used to conduct Suppression of Enemy Air Defense (SEAD) operations, coordinate and adjust indirect fire, conduct reconnaissance and security operations, conduct offensive and defensive air combat, destroy enemy communication and logistical assets, and conduct joint air attacks with TACAIR and Field Artillery (FM1-112, 1991, p. 1-3).

Every attack unit has a unique mission essential task list (METL) that supports parent unit mission priorities and can include a variety of the missions listed above. The METL is a prioritized list of mission tasks that is designed to focus the training efforts of the unit. The METL contains the most critical tasks that must be performed to standard and accomplished to support the mission success of higher echelon units. A task that is common to every ATKHB METL is to conduct deliberate attacks against massed armored and mechanized forces. Therefore, the module portrays attack helicopters used in that primary mission with an emphasis on deep attacks. Deep attacks are directed against enemy forces that are not

currently engaged but could influence division or corps close operations within the next 24 to 72 hours (FM1-112, 1991, p. 3-34). Recall that the definition of "deep" for this module has been expanded to include all attacks against enemy forces not otherwise engaged by ground forces.

The ATKHB is most effective against massed, moving targets and least effective against forces that are in prepared, well-camouflaged positions. Attack battalions cannot conduct missions that require the occupation of terrain but they can deny terrain for limited periods of time by dominating it with direct and indirect fires. Fire support provided by artillery and CAS is important to the survivability of the ATKHB and can be a critical aspect of the mission. Fire support suppresses enemy air defenses, causes armored vehicles to "button up," and enhances the combat power of the unit (FM1-112, 1991).

2. The Organization

The size and organizational structure of an attack helicopter battalion can vary depending on the level at which it exists (EAC, corps, or division), the type of attack aircraft used or the combat missions it will perform. The basic structure of any ATKHB includes subordinate combat and support companies. The attack companies are the combat fighting elements containing the attack aircraft, while the support companies consist of all the other elements. Support elements usually include an aviation maintenance company and a headquarters company with staff sections, a motor maintenance section, mess section, communications section, medical treatment section, and a Class III/V platoon (fuel and ammunition).

3. Deployment for Combat Operations

Attack battalions deploy personnel and equipment to three general locations on the battlefield from which missions are executed and supported: Tactical Assembly Areas (TAA), Forward Assembly Areas (FAA), and Forward Arming and Refueling Points (FARPs). The bulk of the unit is located in the TAA which is generally located in the support area of the major unit parent organization (EAC, corps, or division). The TAA can be considered the

main operating base for the ATKHB. The FAA is a battalion position which is normally forward in a ground maneuver brigade sector that can be occupied by aircraft and a minimum number of support personnel and ground vehicles. FAAs are used for limited periods to support specific missions. They are essentially forward staging areas to provide more flexibility, reaction time, and range for missions. FARPs are used to support all missions. There are two types of FARPs; a Main FARP and a Jump FARP. The Main FARP is located close to the TAA and is more permanent in nature while the J-FARP is temporary and only used for specific missions. The J-FARP is smaller and is packaged with a minimum number of fuel and ammunition support vehicles tailored for a specific mission. FARPs are generally located as far forward in sector as possible but not within range of enemy artillery. The main purpose of the J-FARP is to provide attack aircraft increased range and decrease the time to rearm.

D. ATTACK MISSION PLANNING

Planning a deliberate attack is an involved process; therefore, a standard planning sequence is provided in Department of the Army FM 101-5. In simple terms, planning answers the questions: Where will we fight? What is the threat? What missions will we be expected to execute? How can we best accomplish those missions?

A detailed analysis of the specified and implied mission tasks, the threat, intelligence information, the terrain, and friendly force operational and logistics capabilities is conducted to select the best course of action. The basic elements of an attack plan include:

- *The type of attack to be conducted and desired results.* This defines how the attacking aircraft will be employed and the desired number of enemy vehicles to be destroyed. Desired results are quantified based on accepted definitions of terminology used in mission statements and the commanders intent. Standard definitions include destroy (at least 70% of the enemy force destroyed), attrit (between 30% to 70% of the enemy force destroyed), and disrupt (less than 30% of the enemy force destroyed). Table 2.1 lists the standard attack employment methods.

TYPE OF ATTACK	*DESCRIPTION*
Continuous	Constant pressure is maintained on the enemy force by rotating attack companies so at least one company remains in the battle. Given three attack companies, one is attacking, one is en route, and one is in the FARP. This method provides sustained fires over long periods of time.
Phased	A modification of the continuous attack. One company may begin the attack but the second company is quickly phased into the attack. The third company can be phased into the fight when one of the other companies is low on fuel or ammunition. This method is used to increase the initial firepower of an attack or to save firepower for exploitation.
Maximum Destruction	All attack companies are used simultaneously to overwhelm the enemy with massed fires.

Table 2.1 *Attack Employment Methods.* [FM 1-112, 1991, pp. 3-12 to 3-14].

• *The force size (number of attack aircraft) and appropriate weapons load required to accomplish the mission.* The force size is determined by the number of aircraft required to destroy a specific number of enemy vehicles. Planners usually determine that number based on the number of point target munitions carried per aircraft along with a very conservative probability of a kill.

• *Engagement Area (EA) location in which to kill the enemy targets.* EAs are based on known and forecasted enemy locations and possible movement given the most likely avenues of approach.

• *Battle Position locations (BPs) which provide the best observation and fields of fire based on terrain, weapon systems, and time of day considerations.* BPs are placed to provide flexibility, survivability, and mutually supporting fires. The distance from the target area is far enough to take advantage of weapon standoff ranges but close enough to allow for target identification. There are generally several designated primary and alternate BPs.

• *Attack Routes for ingress and egress to the BPs.* The routes are selected to maximize aircraft survivability. They are determined based on the friendly scheme of maneuver and the perceived enemy threat. The known or suspected enemy ADA sites are avoided when possible. Terrain is also used to mask and conceal movement.

• *FAAs, Jump FARP, and holding area (HA) locations are designated.* FAAs and FARPs have already been discussed. Holding areas are temporary locations that can be used for short periods (10-15 minutes) of time, primarily for coordination. A flight of attack helicopters may set down in a HA to wait

for refuel at a FARP which is occupied by another flight group or to receive final instructions before occupying a BP.

• *Directives for mission readiness cycle and crew rest plan.* The unit is placed on a work/crew rest cycle to support the mission based on the time of day the attack is to be executed. Most ATKHBs plan to support continuous operations but are most effective at night and must be able to support those operations; an enforced readiness cycle makes that possible.

E. ATTACK MISSION EXECUTION

The mission is executed in accordance with an established set of rules known as Tactical Standard Operating Procedures (TACSOP) supplemented by specific mission orders. Execution may differ slightly from unit to unit but some of the most common practices are addressed below.

1. Actions at the Objective

Actions taken at the objective involve conduct in and around the BPs and Engagement Area; they are the actions that directly affect the targeting and engagement of enemy forces. The main consideration at the objective is *fire control.* Fire control is critical to mission accomplishment and allows the commander to direct fires at selected targets and maximize the number of targets destroyed. Fire control consists of the fire distribution plan, engagement priorities, and target priorities.

Fire distribution is controlled at the battalion, company, and platoon levels and defines how the unit will engage the enemy. The attack helicopter battalion uses BPs, company sectors, EAs, and target reference points to deconflict fires. Figure 2.1 illustrates how a fire distribution plan may look.

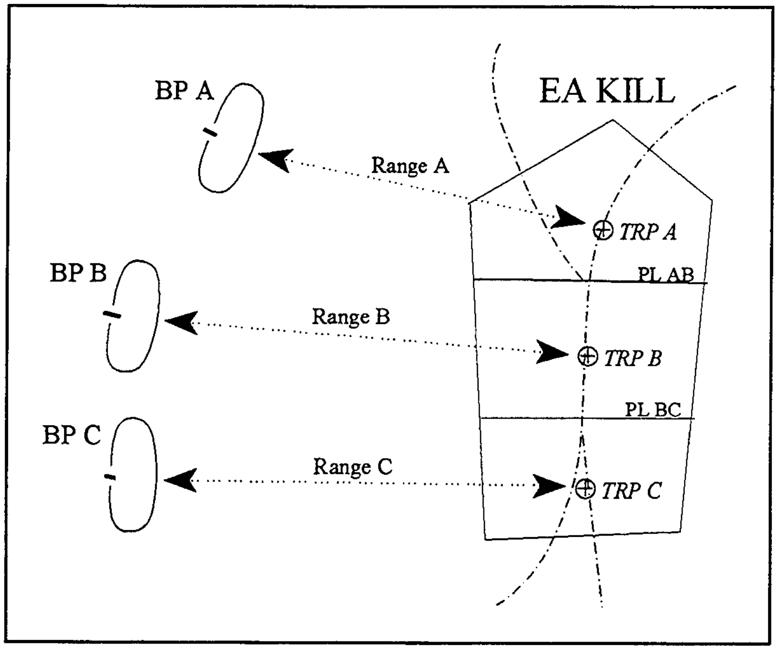

Figure 2.1 ATKHB Fire Distribution. Fires are coordinated with three company BPs and designated sectors within the battalion engagement area. The sectors for fire are separated by phase lines (AB and BC) and each has a target reference point (TRP) to mark the center aiming point.

Engagement and target priorities are also used to control the unit fires. *Engagement priorities* concerns the actions of the individual flight crew during the mission. The general rule is to engage the nearest target that first poses a threat. Target priorities are mission dependent and refer to the types of targets that should receive priority for destruction. (FM1-112, 1991, pp. 3-14, 3-19)

EXAMPLE 2.1: Typical target priorities for an ATKHB.

(1) Air defense artillery, (2) Tanks, (3) Artillery, (4) Mechanized vehicles, and (5) Motorized vehicles.

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2. Actions En Route

Attack helicopter units maneuver in much the same way as ground combat forces except the terrain does not hinder movement. The helicopter force uses terrain along with appropriate flight modes and techniques of movement to maintain security while en route to and from an objective. Flight modes include low-level, contour, and Nap-of-the Earth (NOE). Low-level and contour flight are at higher airspeeds but differ in the altitudes used. *Low-level flight* is conducted at an steady altitude which allows for terrain and obstacle clearance (the aircraft maintain a consistent above sea-level, ASL, altitude). *Contour flight* is conducted with changing altitudes based on the contour of the land (the aircraft follow the contour while maintaining a consistent above ground-level, AGL, altitude). *NOE flight* is maneuver at hovering speeds (generally less than 35 knots) and is as close to terrain and obstacles as safety allows.

There are three movement techniques: traveling, traveling overwatch, and bounding overwatch. *Traveling* is used when speed is important and threat contact is not likely. All aircraft travel at a constant airspeed. *Traveling overwatch* is used when speed is still important but threat contact is likely. Part of the flight travels at a consistent airspeed while the rest travel at necessary speeds to provide overwatch, covering key terrain that may be occupied by the enemy. *Bounding overwatch* is used when threat contact is expected and speed is not as important as survival. The aircraft elements leap-frog in a manner so that one element, the overwatch element, is in a cover and concealed position to monitor the progress of the bounding element. (FM1-112, 1991, pp. 4-6 and 4-7)

F. COMBAT SERVICE SUPPORT

Service support of attack helicopter operations is a demanding task that requires extensive planning and coordination. Every attack unit has the capacity to stock a certain level of supplies but that capacity is limited and supplies are consumed quickly during combat operations. Unlike other maneuver forces, the ATKHB can be tactically employed anywhere within the division's or corps' area of operations. Therefore, the ATKHB depends on CSS from its parent aviation brigade and the division and corps support commands. Attack

helicopters will require fuel and ammunition resupply every 1½ to 2 hours and maintenance requirements will depend on the operational tempo (the number and duration of missions for a given cycle). Successful mission support depends on how well the three critical classes of supply are integrated into the tactical plan. These critical classes are fuel, ammunition, and maintenance repair parts. (FM1-112, 1991, pp. 6-1 to 6-2)

Fuel requirements are determined by daily and mission needs. Daily needs are determined by multiplying the estimated daily hours each type of aircraft will fly by the consumption rate of the aircraft. That figure is then multiplied by the total number of that aircraft type in the unit. The daily fuel quantity required is the sum of the totals by aircraft type. Mission needs are determined the same way, however, mission available aircraft totals are used. Mission needs are used primarily to determine FARP and J-FARP requirements and to modify daily estimates.

Fuel is generally throughput with corps tankers and delivered to divisional support battalion fuel depots. ATKHB fuel tankers then pick up fuel from designated support battalion fuel depots within the division support area. (FM1-112, 1991, p. 6-3)

Ammunition needs are determined in much the same way. A daily estimate is determined or directed based on forecasted missions. Specific mission requirements are then used to update daily estimates. Ammunition is issued from Ammunition Transfer Points (ATPs) within each echelon of command: theater, corps and division. (FM1-112, 1991, pp. 6-4 to 6-5)

Maintenance repair parts requirements are determined from aircraft hours flown. There are parts that are routinely required and forecasted and parts that are not planned and unforecasted. The operational tempo of the unit determines the repair rate and type of required repair parts, but this is also influenced by the availability of maintenance personnel. Depending on the level of maintenance required (unit, intermediate, or depot level), an aircraft may be evacuated to another (higher echelon maintenance) unit for repair.

Attack helicopter units plan and execute missions based on the number of Mission Capable (MC) aircraft. The aircraft that are Not Mission Capable (NMC) are in some maintenance status that precludes there use during a mission. Some of the NMC aircraft are

in planned or routine maintenance while others are in maintenance for repair. Every unit has maintenance standards. An AH-64 equipped attack battalion, for example, maintains an 85% MC aircraft availability rate. Proper repair parts planning and forecasting can support the established maintenance standard, even with unexpected maintenance problems.

G. MISSION READINESS CYCLES

Mission readiness cycles are important because they have an impact on the operational tempo of the unit. The mission readiness cycle refers to the 24 hour cycle that the unit maintains to support forecasted missions. The 24 hour or daily cycle is subdivided into different periods which are defined by readiness conditions. This allows the battalion to rest and perform maintenance while supporting projected mission times (FM1-112, 1991, p. 2-15). Table 2.2 outlines standard readiness levels.

LEVEL	*RESPONSE TIME*
1	Immediate Takeoff
2	15 Minutes
3	30 Minutes
4	1 Hour
5	2 Hours
6	More than 2 Hours (Crews in Rest Cycle)

Table 2.2 *Aircrew Readiness Levels.*
[FM 1-112, 1991, p. 2-16]

Attack helicopter units must plan to support continuous, 24 hour, combat operations. Continuous planning is possible but it is impossible for a given battalion to execute attack missions around the clock. The entire battalion may be at the same readiness level or companies may be at different levels depending on the projected missions. In general, most attack helicopter units are on a cycle to support day or night missions and can be expected to conduct a finite number of missions for a given day and/or night period. Most attack missions are conducted at night to increase the survivability of the aircraft. The cycle may

also depend on the attack aircraft type. An AH-64 equipped battalion is better suited for night operations than an AH-1F battalion, for example.

III. MODELING ATTACK HELICOPTER OPERATIONS

The modeling formulations in this chapter represent attack helicopter deliberate attacks against targeted units not in contact with other ground forces. The primary role of an attack helicopter unit is to conduct deliberate attacks against hostile armor and mechanized forces. Therefore, that is the mission focus of this thesis.

The underlying assumption that an attack mission is generated, assigned to a specific attack helicopter unit, and has appropriate target information is a necessary foundation for this thesis work. The issues involved in targeting logic and mission generation are beyond the scope of this thesis but are briefly discussed later in this chapter.

The major events that occur in the conduct of an attack helicopter mission are addressed in the sequential order depicted in Figure 3.1. Modeling formulations are presented followed by simple numerical examples using opposing force structures as described in Chapter I.

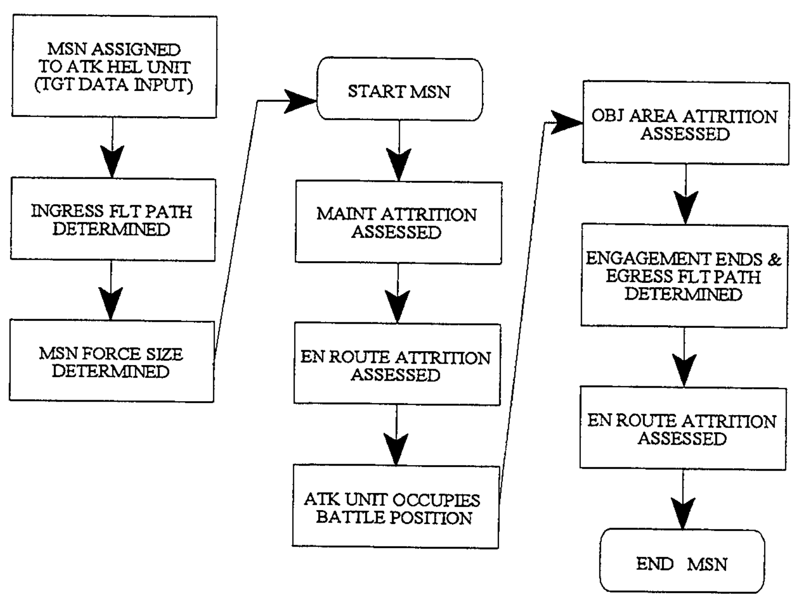

***Figure 3.1** Deliberate Attack Mission Flow*. This flow chart illustrates the major event sequence in the conduct of an attack helicopter deliberate attack mission.

A. UNIT REPRESENTATION

The attack helicopter unit can be represented using two entities, one for all the support elements, and the other for the attack aircraft. The support elements are not explicitly modeled but are considered to exist at a location, such as the tactical assembly area or *base* within the parent unit's support area. The attack aircraft entity is explicitly modeled to provide a means for the attack helicopters to move as an independent unit.

The attack helicopter unit is defined by a unit data file that contains user defined parameters. The base unit data file contains single entries and references to supporting data files of information. Unit data file parameters include the type of information that is depicted in Table 3.1. The ***xxx.dat*** entries highlighted in bold lettering are supporting data files with additional information relevant to that entry. Tables 3.2, 3.3, and 3.4 show examples of supporting data files for the type of attack aircraft, a specific mission type, and the base data file.

The parameters and values in the data files are based on information that can be found in Department of the Army FM 1-112, *Attack Helicopter Battalion*, 1991, and estimations based on the authors familiarity with current attack helicopter operations and knowledge of the topic. Further explanations of parameter definitions and uses will be addressed in subsequent sections as they are used in modeling formulations.

Unit.dat file		
Data	*Definition*	*Example*
side	blue or red	blue
class	id of unit icon class	Attack Helo Aviation
size	id of unit size (BN, BDE, etc..)	BN
unit	id of unit	1-24 Attack Bn
parent unit	id of higher headquarters unit	24ID Avn Bde
planning cycle	planning cycle for missions in hours	12 hrs
day missions	avg number of daylight msn's per 24 hr pd	1
night missions	avg number of night msn's per 24 hr pd	2
base	id of base or tactical assembly area	**ViperBase.dat**
aircraft	id and quantity of attack aircraft	**AH64.dat** / 24
msn priority	msn type / relative mission priority note: This is similar to the way priorities are established for fixed-wing missions in the *JWAEP Ver. 2.0 User Documentation*, 1996, page 14.	**DelAttack.dat** / 100 **HastyAtk.dat** / 80 **Recon.dat** / 20 **Security.dat** / 10 **AirCombat.dat** / 5

Table 3.1 *Attack Helicopter Unit Data.*

AH64.dat file		
Data	*Definition*	*Example*
speed	average mission speed (km per hr)	200 km per hr
range	max range of aircraft in km	400 km
rcs	radar cross section measured 20 deg of the nose (sqr meters)	4.0 m^2 (estimate)
Pfmc	avg % time fully mission capable	0.85
maint failure	avg maintenance failure rate during a mission	0.05
fuel burn rate	avg mission fuel burn rate (gal per hr)	142 gal per hr
jammer effect	jammer effect factor; dimensionless factor based on jammer noise in db Example: if jammer noise level = 13 db, then $L = 10^x$ ($x = 13db \div 10$)	20
munitions	munition / type {A= area , P= point fire } / max range in km	Hellfire / P / 7.5 km 70mm RKT / A / 9 km 30mm / A / 3 km
heavy msn load	munition type / quantity	Hellfire / 16 70mm / 0 30mm / 1200
light msn load	munition type / quantity	Hellfire / 08 70mm / 38 30mm / 1200
estPK	estimated avg PK for missiles (used for msn force size planning)	0.60
time to fire	avg time in seconds to acquire a target and fire a point fire munition	8 secs

***Table 3.2** Attack Helicopter Aircraft Data.*

DelAttack.dat file		
Data	*Definition*	*Example*
Psuccess	K - Destroy (70%), A - attrit (50%), or D - delay (30%)	K = 0.70
wpns load	target type unit / weapons load	armor / heavy mech / heavy motorized / light infantry / light unknown / light
hvy wpns load	munition type / quantity	Hellfire / 16 70mm / 0 30mm / 1200
light msn load	munition type / quantity	Hellfire / 8 70mm / 38 30mm / 1200
Pabort	abort criteria (abort msn if *losses* $\geq A(0) \times (1\text{-}pabort)$ where A(0) is the start msn force size.	0.50
eng cycle	defines the avg engagement cycle activity E - eng tgts, MV - mvmt / M- masked, U- unmasked / avg time seconds / std deviation in seconds	E / U / 15 / 5 MV / M / 25 / 10
BPrange	condition D- day, N- night / avg BP to target range in km	D / 6 N / 4
fire control	amount of fire control R - random, or P - perfect	P
target priority	target vehicle type / priority	ADA / 1 tank / 2 FA / 3 Mech / 4 Motorized / 5

Table 3.3 *Attack Mission Data*

ViperBase.dat file		
CSS parent unit	id of parent combat service support organization	24 ASB
class III	aircraft POL type / daily basic load capacity in gallons	JP4 / 12500 gal MOGAS / 2500 gal Diesel / 2500 gal
class V	ammo type / daily basic load capacity in rounds	Hellfire / 384 70mm RKT / 1824 30mm / 28800
gnd equip	gnd support vehicles / qty	M1009 / 6 11 ton HEMAT / 15 fork lift / 2 2500 gal tanker / 7 cargo HEMAT / 8 5/4 ton commo trk / 13 M1008 / 2 etc...
re-supply cycle	re-supply cycle for forecasts in hours	12 hrs

Table 3.4 *Attack Helicopter Base Data.*

B. UNIT MOVEMENT

The attack helicopter battalion can conduct two types of movement, an administrative movement or tactical road march to reposition the entire unit to a new tactical assembly area or a combat movement to attack a specific target. If the battalion is conducting an administrative or tactical move to a new location (all aircraft and ground support vehicles) then it can move with the parent unit. There is no need to portray independent movement in this case.

Attack helicopters are required to move independently if they are given a mission. Therefore, the attack helicopters are the only ATKHB aircraft or vehicles that are explicitly portrayed when moving in the simulation. The ground support vehicles are implicitly moved with the parent unit but the need to explicitly move certain support vehicles may arise with future JWAEP enhancements. For example, if the logistics module is enhanced to portray the transfer of fuel and ammunition from supply depots to forward units, the ATKHB FARP fuel and ammunition vehicles should be portrayed explicitly.

Explicit movement of helicopter forces can be conducted on a user defined network of nodes and arcs as described in the *JWAEP Version 2.0 User Documentation* (Youngren and Lovell, 1996). The network should represent the major helicopter air avenues of approach in the theater of operations. The helicopter air avenue network is a superset of the ground network (the helicopter network contains the entire ground network and possible additional "air only" arcs and nodes). Air avenues of approach for helicopters are similar to ground vehicle avenues of approach but less restrictive. They generally follow the lower elevations and contours where the use of terrain masking can be maximized to provide cover and concealment and the need to make en route altitude adjustments is minimized.

A network "shortest path" algorithm is used to define a flight path from the helicopter tactical assembly area or base to the intended target location. The algorithm selects the flight path that minimizes the total risk or cost from the base to the designated target node that does not exceed the flights maximum combat range. The same procedure is executed following an attack to determine the egress flight path from the BP at the target area back to the base.

The total risk for a given flight path is the sum of the cost for each path segment. A flight path segment is an arc or a node with an associated distance. The path segment cost is the sum of the weighted arc distance and the weighted ADA threat level. The arc distances and threat levels are weighted to portray relative priority in determining the path. The same principle is used in Hua-Chung Wang's Master's Thesis, *Development and Implementation of Air Module Algorithms for the Future Theater Level Model*, March 1994. The algorithm is in the form of a modified label-correcting algorithm with a worst case complexity of $O(|N| |A|)$ using Big-O notation (Ahuja, et. al., 1993, p. 140).

The label-correcting algorithm assumes a directed network is used with positive arc lengths and risk levels, however, the algorithm works for both directed and undirected networks. A predecessor index is used to define a predecessor graph. The predecessor graph will contain a unique directed path from the source node, *S*, to every node *k* that is within the combat range of the flight and has the lowest level of risk. If an optimal path exists that is within the combat range of the flight, it can be easily determined from the predecessor graph.

The complete algorithm is shown in Appendix A, Network Shortest Path Algorithm, and the following parameters are used:

- Algorithm Input:

G = (N, A) {the network in linked node, forward star (FS) arc adjacency list}
S {the starting node}
T {the ending node}
R {combat range of the attack helicopter unit - ½ of the total mission range}
d_{ij} {distance from node *i* to node *j* in kilometers}
w_d {weight or relative importance of distance}
w_t {weight or relative importance of threat where ($w_d + w_t = 1.0$) }
t_{ij} {perceived ADA threat level from node *i* to *j* on a scale of 0 to 1, 1 being the highest threat}

- Variables:

$$TD(i) = \sum_{(i,j) \in Pred\ List} d_{ij}$$ {total distance at node *i* based on the optimal path from the predecessor list}

$$TR(i) = \sum_{(i,j) \in Pred\ List} r_{ij}$$ {total risk at node *i* based on the optimal path}

$$r_{ij} = w_d\left(\frac{d_{ij}}{R}\right) + w_t t_{ij}$$ {arc (*i,j*) cost}

Note: The calculation for cost is based on weighted values for arc distance and threat level. The distance is normalized for combat range *R* to give it the same relative order of magnitude (0 to 1) as the threat level.

- Output:

MinPath {the path from the predecessor list}
Dist {total dist from *S* to *T* based on optimal path}
Total Risk {total ADA risk from *S* to *T* based on optimal path}

The label-correcting algorithm is written in a form that assumes all network nodes have no associated distance or risk level. If a given node *i* has an associated distance (*d*), it can be split into two nodes, *i'* and *i''*. The resulting arc (*i'*, *i''*) can now be assigned the values associated with node *i*. Figure 3.2 illustrates an example of node splitting. (Ahuja, et. al., 1993, p. 41)

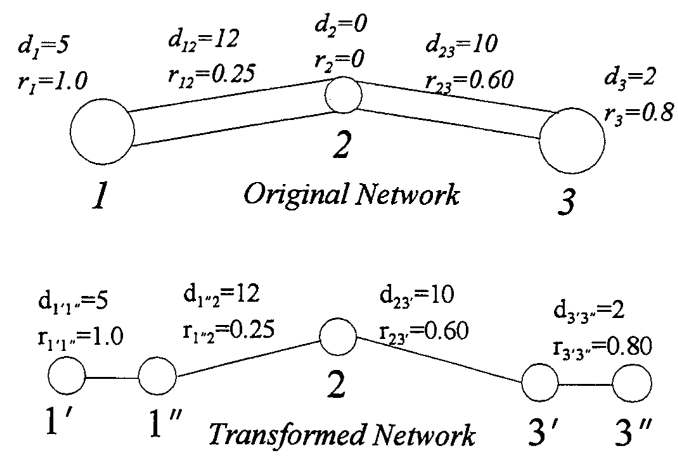

Figure 3.2 *Network Conversion.* The technique of node splitting is used on nodes with associated areas. Node 2 in the diagram is only a connector node with no associated area and did not need to be split.

The threat level for a given segment in the network is calculated using the same basic form as described in Hua-Chung Wang's Master's Thesis, *Development and Implementation of Air Module Algorithms for the Future Theater Level Model*, 1994. The threat level for each arc, t_{ij}, is the proportion of area that is covered by the sum of lethal ADA weapon system areas on a given arc or node. The equation used is

$$t_{ij} = \min \left\{ \frac{\sum_k (PK_k \times AREA_k)}{AREA_{ij}} \;,\; 1.0 \right\} \tag{1}$$

where $AREA_{ij} = \begin{cases} length \times width & for\ arcs \\ \pi\,(node\ radius)^2 & for\ nodes \end{cases}$

PK_k = *estimated probability of kill for ADA weapon* k, and

$$AREA_k = \begin{cases} (ADA\ range) \times (\text{arc}\ width) & for\ arcs \\ \pi\,(ADA\ range)^2 & for\ nodes \end{cases}$$

The calculations for $AREA_k$, the ADA weapon k area coverage, are based on the assumption the weapons are located at the center point of the node or associated arc - this provides for maximum ADA coverage which is the most conservative estimate. The calculation for area coverage on an arc uses a simplified rectangular approximation to the actual area that would be covered based on a circular coverage area.

The ADA area is weighted by its estimated probability of kill, PK_k, for the given ADA weapon type k against any target of interest. The probability used is only a planning factor based on the perceived capabilities of the weapon. The true probability of kill (a different value from the estimated PK_k) based on the ADA weapon type, aircraft type, and ammunition used, will be used for actual attrition during a mission. (Wang, 1994, p. 8)

EXAMPLE 3.1: Threat Level. Given a threat SA-13 ADA weapon system with an estimated pk of 0.60 and a range of 8 km, calculate the threat level if it is located on an (a) node with radius = 15 km, and (b) arc with length = 20 km and width = 5 km.

(a) for the node: $AREA_{node} = \pi(15\,km)^2 = 706.86\,km^2$

$AREA_{SA9} = \pi(8\,km)^2 = 201.06\,km^2$

$\therefore \quad threat\ level\,(t_{node}) = \frac{(estPK = 0.6) \times (201.06)}{706.86} = 0.17$

(b) for the arc: $AREA_{arc} = (20\,km) \times (5\,km) = 100\,km^2$

$AREA_{SA9\ on\ arc} = (ADA\ rng = 8\,km) \times (\text{arc}\ width = 5\,km) = 40\,km^2$

$\therefore \quad threat\ level\,(t_{arc}) = \frac{(estPK = 0.6) \times (40)}{100} = 0.24$

C. MISSION FORCE SIZE

The mission force size is calculated at the start of every new mission. It is based on the number of attack helicopters in the unit, current unit maintenance posture, the perceived number of vehicles in the targeted enemy force, the weapons load for the mission type and target category, and the mission success criteria. The number of aircraft at the start of the mission will be limited to the minimum number of aircraft required to destroy the specified number of enemy vehicles subject to aircraft availability. Therefore, the total battalion force size for a mission is determined without regard to subordinate company size formations

within the battalion. It is assumed that subordinate company units will be task organized accordingly.

The number of mission aircraft, $A(0)$, is determined by

$$A(0) = \min \left\{ A_{req}, A_{FMC} \right\}. \tag{2}$$

The available number of aircraft, A_{FMC}, is the rounded down integer value of the number of aircraft type a available multiplied by the user defined fully mission capable (FMC) maintenance rate:

$$A_{FMC} = \left\lfloor (TOT\ A/C_a) \times (\%FMC_a) \right\rfloor \tag{3}$$

The required number of aircraft, A_{req}, is calculated based on the perceived number of enemy combat vehicles, the mission success criteria as defined for the type mission (destroy, attrit, or delay), and the aircraft weapons load (heavy or light). It is assumed the targets assigned to a given attack battalion are realistic. The target size, in terms of the number of targeted vehicles, should not exceed the capabilities of the attack battalion. If the target is much larger than the attack battalion's capabilities ($A_{req} >> A_{FMC}$), more than one attack battalion should be assigned the mission. An alternative method would be to have the attack battalion execute two attacks on the target. However, it would be unreasonable to have an attack battalion execute more than two back to back attacks on the same target.

The weapons load is based on the target category and the type of mission performed. There is a trade off between area fire munitions like rockets and 30mm rounds that are used more for suppression against lightly armored vehicles and point fire munitions like Hellfire missiles that are used to kill heavily armored vehicles like tanks. For example, if the target is a heavily armored tank regiment and the mission is a deliberate attack, the weapons load would be heavy; i.e., maximum point fire munitions are carried. A light load is typically a mix of point fire and area fire munitions and is more appropriate for attacks against lightly

armored forces or in cases where the threat situation is not clear.* The aircraft weapons load and specific munitions configuration is based on the target description and aircraft type as depicted in Table 3.2, Section A.

Calculations for the number of aircraft required are based only on the number of point fire munitions carried per aircraft. Therefore, the required number of aircraft is

$$A_{req} = \left\lceil \frac{(Tot\ Veh) \times (\%SUCCESS_m)}{(NMissles_a) \times (EstPK_a)} \right\rceil \tag{4}$$

where A_{req} is rounded up to the nearest integer value and

Tot Veh = total enemy vehicles (based on perceived information),

$\%SUCCESS_m$ = mission success criteria percentage for mission type m,

$Nmissiles_a$ = number of point fire munitions per aircraft type a based on weapons load,

$EstPK_a$ = estimated probability a missile hits and kills a given target.

All the parameters above, except for the number of targeted enemy vehicles, are from the appropriate attack helicopter or mission type data files.

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* In the context of JWAEP, which maintains an explicit probability list for every possible unit set at a node or arc, it will be necessary to develop rules that specify the dominant target type(s) (e.g., those with a cumulative probability of 75%) and determine the mission load based on them.

EXAMPLE 3.2: Mission Force Size. The mission is to destroy an enemy tank regiment with 135 combat vehicles. Each attack helicopter (AH-64) is armed with sixteen hellfire missiles (heavy load based on Armored unit target).

STEP 1: Determine number of aircraft available for mission.

Eqn (3) $A_{FMC} = (24 \text{ AH-64's}) \times (\% \text{ FMC} = .85) = 20.4$ $\therefore$ 20 aircraft

STEP 2: Determine number of aircraft required to destroy 70% of the vehicles.

Eqn (4) $A_{req} = \frac{(135 \ vehs) \times (\%SUCCESS = .70)}{(16 \ Hellfires \ per \ A/C_a) \times (EstPK_a = .60)} = 9.84375$ $\therefore$ 10 aircraft

STEP 3: Determine number of aircraft for the mission.

Eqn (2) $A(0) = \min \{ A_{FMC} = 20 \, , A_{req} = 10 \}$ $\therefore A(0) =$ 10 aircraft

Note: Assumes each aircraft has the opportunity to fire all missiles and fire distribution between each aircraft is perfectly coordinated. The estimated P{kill} = .60 is an accepted planning value that is commonly used for AH-64's. (FM1-112, 1991, p. C-19)

The mission abort criteria is calculated once the mission force size is determined. The abort criteria defines the minimum number of aircraft required for the mission. If at any time during the mission the number of aircraft in the flight becomes less than or equal to the abort criteria the mission is stopped at that point and the flight returns to base. The abort criteria is calculated as $ABORT = A(0) \times \%Abort$, where *%Abort* is a user defined parameter for the unit and mission type. Each attrition adjudication, except for an egressing flight, is followed by a mission abort check to determine if the attack helicopter mission continues.

If $A(I) > A(0) \times \%Abort$, then the mission continues.

If $A(I) \leq A(0) \times \%Abort$, then the mission is ended and the flight returns to its base.

A flight that reaches its abort criteria while traveling en route to the target area will return to base along the same flight path. An attack helicopter force reaching its abort criteria while occupying a battle position returns to base along a new path as determined using the flight path algorithm to minimize the threat and distance traveled.

D. ATTRITION ADJUDICATION

There are three types of attrition that are addressed for modeling purposes. One is maintenance related and the other two are due to hostile forces. All involve the loss of mission aircraft but maintenance losses are temporary subject to repairs while losses due to hostile fire are permanent. The hostile attrition process is simplified by limiting the possible engagements between the attack helicopter force and hostile forces. Engagements or *force interactions* are a function of the attack helicopter force disposition (traveling en route or at the objective area in fixed battle positions), munitions carried, the mission, and the type of opposing force.

1. Maintenance Failure Attrition

Maintenance failure or non-hostile attrition is assessed at the start of every mission. It represents the number of aircraft that may be lost during the mission due to some maintenance related problem. A one time adjudication takes place at the start of each mission. A random draw from a binomial distribution is used to determine maintenance losses based on a given input parameter, $Pmaint_a$; the probability that aircraft type a is lost due to maintenance during the mission (aircraft in maintenance before the mission are accounted for in A_{FMC}). Recall that $A(0)$ is the force size at the start of the mission.

$$Let\ X \sim Binomial(\,n{=}A(0),\ p = Pmaint_a\,)\ ;\ then\ A(0) = A(0) - X$$

The maintenance losses, X, are all assumed to be repairable and/or recoverable and are therefore only deleted from the current mission. They are considered to be available for subsequent missions.

2. En Route Attrition

En route attrition is defined as the destruction of traveling attack helicopters by hostile forces. Hostile air defense weapon systems are the major threat but threat fixed wing air and attack helicopters conducting air-to-air combat missions can also cause attrition. The attrition is one sided with respect to hostile ADA - only the ADA weapons fire at aircraft.

Attack helicopters only engage targets with offensive fires from fixed battle positions. Any en route fires are assumed to be defensive and primarily suppressive in nature having negligible effects on the enemy. Therefore, suppressive fires against ground targets en route are not considered for modeling purposes. The only exceptions are defensive fires against hostile attacking air forces (fixed wing or helicopters). Figure 3.3 portrays the forces which can interact during the en route phase.

En route attrition is adjudicated sequentially with air to air engagements following surface to air engagements. It is assumed that surface to air engagements are most likely to occur first and air to air engagements will not occur at the same time as surface to air engagements.

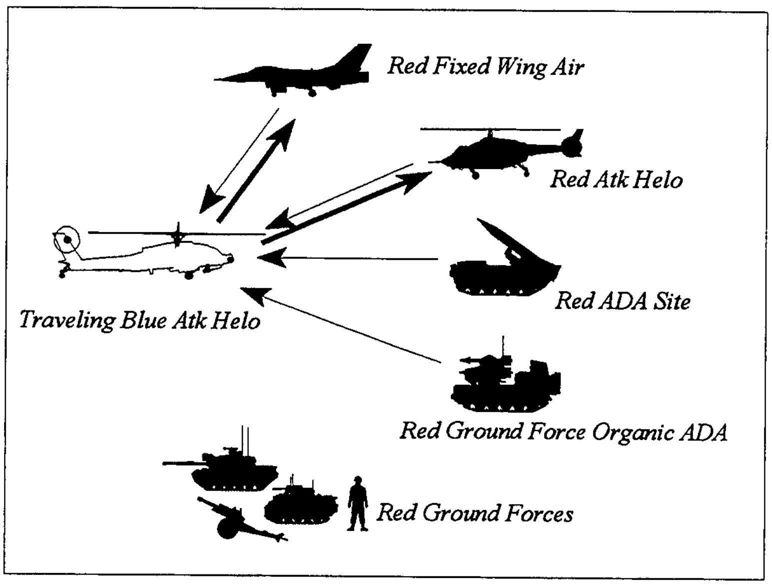

***Figure 3.3** Possible En Route Attrition Interaction.* The thick arrows indicate the enemy force type the attack helicopter unit can engage en route. The thin arrows show the enemy forces that can engage the attack helicopters.

a. Surface to Air

An ingressing or egressing attack helicopter force follows an air axis of advance on designated routes. Most air axes contain multiple air routes. Helicopters fly at relatively slow airspeeds (between 35 and 120 nautical miles per hour) and at altitudes typically below 200 feet above ground level. The slow speed of the aircraft may be advantageous for the ADA unit but the low altitude and increased maneuverability of the helicopter make it a difficult target to acquire and engage. Terrain masking can also limit the ability of the ADA unit to fire at the aircraft. Figure 3.4 illustrates an example of an air axis with multiple routes that crosses through the lethal range of a hostile ADA unit.

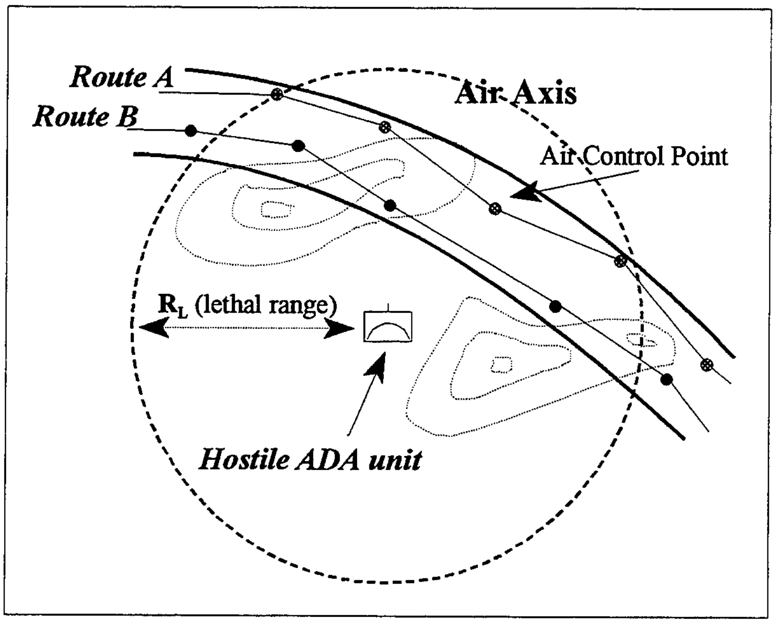

***Figure 3.4** Air Routes thru an ADA Lethal Range Fan.* The Air Axis with two air routes passes through the lethal range (aircraft can be acquired and engaged) of a hostile ADA unit. The terrain as depicted will provide some masking of low flying aircraft which limits the time the ADA unit can acquire and engage targets.

Another factor that can have a limiting effect on the abilities of the ADA unit is onboard aircraft survivability equipment. Many helicopters have electronic radar jammers, chaff, and other devices to combat threat radars and missiles.

The en route attrition adjudication calculation for ADA systems versus a flight of attack helicopters takes place once for each arc and node along a designated flight path if that segment of the air axis crosses the lethal range of an ADA weapon system. The attrition calculation accounts for the entire time the aircraft in the flight are within the lethal range. Therefore, if the lethal range of an ADA system covers more than one arc or node on the selected flight path then attrition is only calculated once.

The lethal range of an ADA weapon system is defined as the minimum of the adjusted fire-control radar range and the maximum slant range for the missile fired. The acquisition radar range for the given ADA weapon system is not considered in determining the lethal range. It is assumed the probability of a given acquisition radar's ability to detect and track a low level flight of helicopters beyond the range of the fire-control radar is sufficiently low enough to be considered insignificant.

The adjudication process involves (1) calculating the adjusted fire-control radar range and determining the lethal range of the ADA system, (2) determining the total engagement time, (3) calculating the possible number of shots the ADA weapon makes, and (4) calculating the number of aircraft destroyed in the flight.

Step 1 - Lethal Range. The lethal range is defined as the range at which a given ADA weapon system and its associated fire-control radar system can engage a target and is determined based on:

$$R_L = \min \{ R_{FC}, R_{MSL} \} \tag{5}$$

where R_{FC} = adjusted fire-control radar range, and

R_{MSL} = the maximum slant range for the ADA missile fired.

The adjusted fire-control radar range is dependent on the characteristics of the radar system and the target. The basic range equation as described by Gershon J. Wheeler in *Radar Fundamentals*, 1967, pages 25-26, is

$$R_{\max} = \left(\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{\min} L} \right)^{1/4}$$

where R_{max} = max range at which target is detectable
P_t = radar power
λ = radar frequency
A_e = effective area of the radar receiving antenna
σ = radar cross sectional area of the target (RCS)
S_{min} = minimum detectable signal
L = system signal loss factor.

If the basic radar equation is modified so $R_{\max} = C \left(\frac{\sigma}{L}\right)^{1/4}$, where $C = \left(\frac{P_t A_e^2}{4\pi \lambda^2 S_{\min}} \right)^{1/4}$, it follows that $R_{\max} \propto \left(\frac{\sigma}{L}\right)^{1/4}$.

The above proportional relationship is used to determine the adjusted fire-control radar range, R_{FC}. The calculations are based on the *radar cross sectional area of the entire flight* of aircraft, σ_{FLT}, and the *signal loss factor for the flight due to the effects of jammers,* LJ_{FLT}.

There are many sources of loss in a system that reduce the transmitted and received signals. The system loss is the sum of all losses and is a number greater than the unity equivalent to the system loss in decibels. For example, if the system loss is 13db, the loss factor is 20 (10 log 20 = 13). The type of loss attributed to the effects of jammers is called a collapsing loss. Jammers produce noise that can effectively mask certain signals by reducing the signal-to-noise ratio which reduces receiver sensitivity. The loss due to that degradation is an example of a collapsing loss. (Wheeler, 1967, pp.32,33)

The adjusted fire-control radar range is calculated using the formula:

$$R_{FC} = R_{FC}^1 \left(\frac{\sigma_{FLT}}{LJ_{FLT}} \right)^{1/4} \tag{6}$$

where $\sigma_{FLT} = \sum_{i=1}^{n} \sigma_i$, $LJ_{FLT} = \left(\sum_{i=1}^{n} L_i^2 \right)^{1/2}$, and

R_{FC}^{1} = max range of radar system against a target with RCS equal to one ($\sigma_1 = 1\ m^2$)
n = total number of aircraft
σ_i = the RCS for ith aircraft
L_i = signal loss due to the ith aircraft jammer.

The form of the equation for LJ_{FLT} was adopted from Air Force Studies and Analyses Agency, *Thunder Analyst's Manual*, May 1994, page 12-97, and is analogous to E_G in Equation 12-7 in the manual.

Step 2 - Engagement Time. The ADA engagement time, TE, represents the average length of time that the ADA weapon can actively fire at the flight. It is calculated based on a reduction of the total time the flight is within the lethal range of the ADA system using the formula:

$$TE = (PLOS \times T) - (TD + TR) \tag{7}$$

where T = total time within the ADA lethal range
TD = time it takes to detect the flight
TR = time it takes the weapon to get ready or prepare to fire, and
$PLOS$ = probability that line of sight exists between the ADA weapon and the flight.

Assuming the lethal area around an ADA weapon system can be approximated by a circle and given the lethal range, R_L, a random draw from a uniform distribution, $X \sim U(0, R_L)$, is used to determine the point at which the aircraft penetrates the circular lethal area. The total time within the area $T = d / S$ where the distance traveled within area $d = 2\sqrt{R_L^2 - x^2}$ and S = the aircraft average combat speed. A graphical illustration is shown in Figure 3.5 that depicts the geometry used to calculate the distance d.

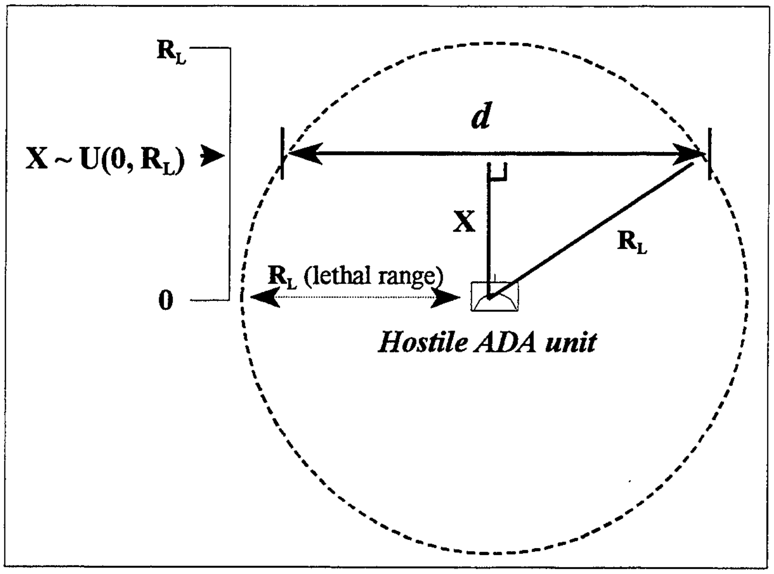

Figure 3.5 *Flight Travel Distance Within ADA Lethal Range.* The distance, *d*, which an ATKHB flight travels within the ADA lethal range is calculated using simple geometry where $d = 2\sqrt{R_L^2 - x^2}$.

The detection time is determined using a random draw from an exponential distribution where $TD \sim Exp\ (\lambda)$ and the rate is a user defined input for the given ADA system. The ready time or time it takes the ADA weapon to prepare to fire, *TR*, is also a user defined parameter based on the average time for the specific system. Obviously, if the sum of the detection time and the ready time is greater than the adjusted total time, the engagement time equals zero.

$$If \quad (TD + TR) > (T \times PLOS) \quad then\ TE = 0.$$

Terrain masking is accounted for by using *PLOS*, the probability that line of sight exists between the weapon and intended target. *PLOS* is a function of the terrain type and the range to target. Studies conducted for the U.S. Army indicate the *PLOS* can be approximated using the Weibull distribution with parameters α and β that vary based on the terrain type. (Military OR Analyst's Handbook, 1994, p. 2-24)

Step 3 - Number of Shots. The total number of shots, *Nshots*, the ADA weapon can fire in the given period of time, *TE*, is calculated based on the specified ADA weapon system rate of fire, and the total number of missiles available, *Ntot:*

$$Nshots = \min \{ [(Weapon\ Rate\ of\ Fire) \times TE] , Ntot \} \tag{8}$$

The total number of missiles available, *Ntot*, is defined as the number of missiles on the launcher that are ready to fire and the number of missiles that are ready for immediate reload. It is assumed that the weapon rate of fire takes into account the reload time for missiles that are not on the launcher ready to fire.

Step 4 - Number of Kills. The final step is to determine the number of aircraft that are destroyed by the ADA system. A random binomial draw based on the number of missiles fired and the probability an individual aircraft is killed by a single missile, *SSPK*, is used to determine losses when the number of missiles fired is less than or equal to the number of aircraft, $Nshots \leq A(i)$. It is assumed that each missile is fired at a different aircraft.

$$Let\ L(i) \sim Binomial\ (n = Nshots,\ p = SSPK);\ then\ L(i) = aircraft\ losses$$

The single shot probability of a kill, SSPK, is the probability an individual aircraft is killed by one shot from the ADA weapon. The $SSPK_{k\text{-}a}$ value is a user defined parameter for the specified ADA weapon type k firing against aircraft type a. (Thunder, 1994, p. 12-95)

If the number of missiles fired is greater than the number of aircraft, $Nshots > A(i)$, then the number of missiles fired at each aircraft is distributed as evenly as possible. The minimum number of missiles allocated per aircraft is calculated as $Nmin = \left\lfloor \frac{Nshots}{A(i)} \right\rfloor$. *Nmin* is then allocated to each aircraft. The remaining missiles, if any, are distributed one per aircraft until all are allocated. For example, if 10 missiles are fired at 7 aircraft, then *Nmin* = 1 and missiles are allocated as follows:

	Aircraft						
	1	*2*	*3*	*4*	*5*	*6*	*7*
Initial missile allocation (Nmin each)	1	1	1	1	1	1	1
Remaining missile allocation	1	1	1				
Total Missiles	2	2	2	1	1	1	1

The number of kills is then calculated based on a Bernoulli trial for each missile fired. The losses for the current flight path segment *i* are determined by:

$$L(i) = \sum_{j=1}^{A(i)} Kill_j \qquad where\ kill_j = \begin{cases} 1 \ \ if\ U(0,1) > PK_j \\ 0 \ \ otherwise \end{cases} \tag{9}$$

The number of aircraft that start the next, *i+1*, segment is calculated by subtracting losses from the number of aircraft at the start of the current path segment:

$$A(i+1) = A(i) - L(i). \tag{10}$$

EXAMPLE 3.3: Surface to Air Attrition. Determine the number of aircraft losses given a flight of 10 AH-64 each with a RCS = 4.0 m^2 and a jammer with an effective rating of 20 , and a SA-9 ADA weapon system with 4 missiles available, a rate of fire of 1 missile every 5 secs, missile range 8 km, fire-control range 10 km and an acquisition rate λ = .03 min^{-1}, and crew ready time approximately 8 seconds. The estimated PLOS for the terrain is .05.

STEP 1: Determine lethal range.

RCS for flight $\sigma_{FLT} = \sum_{i=1}^{10} 4.0\,m^2 = 40\,m^2$

and flight signal loss due to jammers $LJ_{FLT} = \left(\sum_{i=1}^{10} 20^2\right)^{\frac{1}{2}} = 63.25$

Eqn (6) $R_{FC} = (10\,km)\left(\frac{40}{63.25}\right)^{\frac{1}{4}} = 8.9\,km$,

therefore Eqn (5) $R_L = \min\{8.9\,km, 8\,km\} = 8\,km$

STEP 2: Determine the engagement time.

let X ~ U(0,8km) = 5 km

total time within range $T = \frac{2\sqrt{(8^2-5^2)}}{200\,km/hr} \times 3600\ sec/hr = 225\ secs$

let TA ~ Exp(.03) = 30 secs and TR = 8 secs

Eqn (7) $TE = (0.50 \times 225) - (30 + 8) = 74.5\ secs$

STEP 3: Determine the number of shots.

Eqn (8) $Nshots = \min\{[(0.2\ per\sec) \times 74.5\ secs = 14.9], 4\ msls\} = 4$

STEP 4: Determine the number of aircraft destroyed assuming SSPK = 0.65.

since $Nshots \le A(i)$, let L ~ Bin(n = 4, p =.65) = 2 aircraft

$\therefore$ Aircraft surviving to next flight path segment = 10 - 2 = <u>8 aircraft</u>

b. Air to Air

Air to air combat only occurs if a *Defensive Counter Air* or *DCA* Mission as described in the *JWAEP Version 2.0 User Documentation,* Section V: Air War, is generated against the flight of attack helicopters.

If a DCA Mission has been generated and the intercepting flight of aircraft has acquired the attack helicopter flight, it is assumed the attacking force acquires, identifies, and fires on the attack helicopter defending flight first. The defending attack helicopter flight automatically detects the attacking flight after it fires and is then given the opportunity to

respond. The defending flight can disperse and seek cover and concealment or return fire based on the calculated advantage ratio.

The advantage ratio, ADV(atk), measures the relative advantage the attacking force has over the defending flight in terms of speed and weapons ranges. The ratio:

$$ADV(atk) = \alpha\left[\left(\frac{R_{atk}}{R_{def}}\right) \times \left(\frac{S_{atk}}{S_{def}}\right)\right] \tag{11}$$

where R_i is the max air to air munition range of the attacking or defending force i, and S_i is the avg combat speed of the attacking or defending aircraft type. The parameter α is user defined and can be used to weight the attack advantage ratio if necessary. Depending on the aircraft type and mission, the advantage ratio may need to be adjusted to make helicopters more or less willing to return fire since it is being compared to a fixed value as discussed below. The default setting for the weight is $\alpha = 1$ unless the mission type dictates otherwise.

If a flight of helicopters is attacked by a superior force the most advantageous tactic is to disperse and seek cover and concealment (break contact and get away). A "superior force" is defined as a force that has at least a three to one advantage over the defender. Therefore, the defender will only return fire if ADV(atk) < 3.

If ADV(atk) < 3, then the defending helicopter flight returns fire

The use of the advantage ratio helps to minimize engagements between defending helicopters and fixed wing attacking forces. If an attack helicopter flight is attacked by fixed winged force the accepted tactic is for the helicopter flight to scatter, seek cover and concealment, and break contact. If a helicopter force is attacked by another helicopter force, however, it may be necessary for the defending helicopter force to return fire to facilitate breaking contact. The advantage ratio for opposing helicopter forces will normally be less than three which allow both to engage each other.

Assuming opposing forces come into contact as the result of an air combat mission (there are no random air to air meeting engagements modeled for air attacks against

helicopters), air to air attrition is adjudicated in two steps, (1) the attacking force fires and defender losses are assessed, and (2) based on the calculated advantage ratio, the defending force may fire and the attacker losses are assessed. It is assumed that the defending force detects the attacking force only after being fired upon. The air to air engagements against helicopters are limited to one engagement per side which is a simplifying assumption based on the relatively uncommon occurrence of air to air engagements. Therefore, the attrition calculations will only occur at most twice per mission for an en route air to air engagement.

Air to air losses are determined the same way en route surface to air losses are determined. The main difference is the use of an SSPK value derived from an aggregated probability of kill. The single shot probability of kill or *SSPK* is equivalent to an aggregated weapons *PK* (Eqn 12). The aggregated weapons probability of kill, $PK_{agg}(a)$, is for a single aircraft and uses the same form as described in the Air Force Studies and Analysis Agency *Thunder Analyst's Manual*, Version 6.1, May 1994, page 13-111. The formula used is:

$$SSPK \equiv PK_{agg}(a) = \sum_i PK_i(a) \times FL_i \qquad (12)$$

where $PKi(a)$ is the probability of kill for weapon type i against aircraft a, and FL_i is the fractional number of launches for weapon i.

Example 3.4: Aggregate Probability of Kill. A MIG-23 is carrying 2 AA-2 and 2 AA-7 missiles and makes four launches per engagement. Calculate the SSPK if the weapons have a 0.6 and 0.5 PK respectively.

STEP 1: Determine the fractional launches for each weapon.

for the AA-2: 2 weapons / 4 launches = ½

for the AA-7: 2 weapons / 4 launches = ½

STEP 2: Calculate the SSPK.

Eqn (10) $SSPK = PK_{agg}(a) = (0.6)½ + (0.5)½ = \underline{0.55}$

The number of shots an attacking flight can deliver is based on the number of aircraft in the flight and the number of launches each aircraft can make:

$$NShots = (NFlight_f \times NLaunches_f) \tag{13}$$

where $NFlight_f$ = number of aircraft in the flight that is firing,

$NLaunches_f$ = number of launches per engagement.

Losses are then determined following the same steps as outlined for en route surface to air losses. The binomial draw is used in cases where $Nshots \leq A(i)$ and Bernoulli trials for each aircraft are used if $Nshots > A(i)$; the same logic as discussed previously is used to allocate missiles per defending aircraft.

EXAMPLE 3.5: Air to Air Attrition Adjudication. Given an attacking flight of two MIG-23 aircraft (as described in Example 3.3) against a flight of 10 AH-64 attack helicopters, determine the losses for each side. Assume the flights are in contact.

STEP 1: Determine defending AH-64 losses from MIG-23 attack.

Ex 3.3 $SSPK = .55$

Eqn (13) $NShots = (2\ MIGs) \times (4\ launches) = 8\ shots$

Nshots=8 $\leq$ A(i)=10 therefore the binomial draw can be used; let X ~ Bin(n=10, p=0.55) = 5 $\therefore$
10-5 = 5 AH-64s survive attack

* Given 3 MIGs, Nshots = 12. Therefore, shots are allocated so 8 aircraft are fired at with one missile each and two aircraft are fired at with two missiles each. The probability of kill for each aircraft is:

Aircraft attacked with one missile: $PK = SSPK$

Aircraft attacked with two missiles: $PK = 1 - (1 - SSPK)^2$

STEP 2: Determine attacker losses if applicable.

Eqn (11) $ADV(atk) = \left(\frac{R_{atk} = 10\ km}{R_{def} = 7.5\ km}\right) \times \left(\frac{S_{atk} = 500\ km/hr}{S_{def} = 200\ km/hr}\right) = 3.33$ ADV(atk) $\nless$ 3

$\therefore$ The defending helicopters do not return fire. There are no attacker losses and the air to air engagement is finished.

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3. Objective Area Attrition

Objective area attrition is defined as the destruction of attack helicopters, ground forces or other air forces as a result of action that takes place while the attacking helicopter forces are in fixed battle positions. Hostile air defense weapon systems and threat fixed wing air and attack helicopters conducting air-to-air combat missions remain a threat to attacking helicopters and can still cause attrition. The major change is the attacking helicopter forces' ability to cause attrition.

Attrition is now two-sided with respect to hostile ADA and threat air, but only one sided against maneuver ground forces. It is assumed that fires from maneuver ground forces against attack helicopters are normally out of range when helicopters are in stand-off battle positions or have negligible effects. Figure 3.6 depicts the possible objective area attrition interactions.

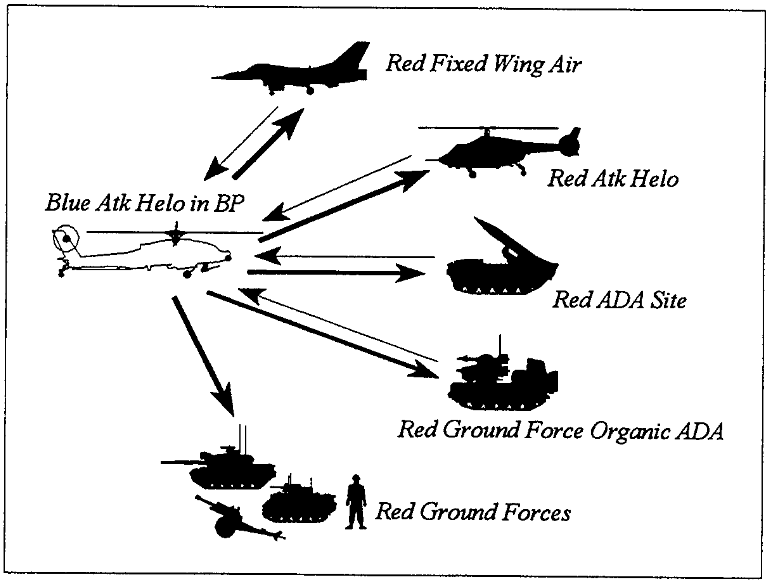

Figure 3.6 *Possible Objective Area Attrition Interaction.*

The dynamics of possible force interactions at the objective area make it feasible for different forces (ground ADA weapons and attack helicopters) to engage each other simultaneously. Therefore, objective area attrition will be adjudicated in time steps based on an engagement cycle to represent nearly simultaneous engagements.

The *engagement cycle* is based on attack helicopter actions in the battle position. The BP is the location from which the attack helicopter engages targets but is also an area that provides cover and concealment from enemy forces and maneuver area for multiple firing positions. Attack helicopters normally unmask to engage targets for a short time, mask and reposition, then unmask to engage targets again. If the attack helicopters are outside the range of any possible threat they can remain unmasked the entire time in the BP but that scenario will not be considered for modeling purposes. The assumption that each attack helicopter will engage targets in accordance with a unmasked engagement and masked movement cycle is used.

The cycle length is determined using a normal distributions and user defined parameters for average unmasked and masked times and standard deviations in the BP.

Let Unmask Time (k) ~ Normal (μ = avg unmask time, σ = std dev unmask time) and
Let Mask Time (k) ~ Normal (μ = avg mask time, σ = std dev mask time)

The total cycle length is the sum of the unmasked and masked time. The total number of cycles $k = \{1, 2, \ldots, K\}$ depend on the number of munitions fired per cycle and the total number of munitions carried or on the mission abort criteria. It is assumed the attack helicopters expend all munitions if the mission abort criteria is not reached.

Another important consideration for objective area attrition adjudication is the range from the BP to the target. The range to target is used as an input to determine appropriate probabilities of kill for aircraft and ground based ADA weapons. The range to target will vary based on individual aircraft positions so a draw from an average distance is used. The range to target distance is a function of the attack helicopter unit's average BP to target distance which is a user defined value for both day and night conditions. This allows the user to define a range that can reflect both weapons standoff ranges and the optical capabilities of the aircraft.

The range, $R_{BP\text{-}TGT}$, is based on a draw from a normal distribution using the user defined average BP to target range found in the mission type supporting data file.

$$Let\ R_{BP\text{-}TGT} \sim Normal\ (\mu = avg\ BPrng,\ \sigma = .2\ \mu)$$

The spread of $R_{BP\text{-}TGT}$ is limited to three standard deviations about the mean to prevent the use of any unrealistic values.

Objective area attrition adjudication is conducted in accordance with engagement cycles but is sequential within each cycle. The attack helicopters attrit the ground force, ground ADA weapons have the opportunity to attrit the attack helicopters, and then air to air attrition is assessed if it applies. The sequential scheme is based on the idea that an attacking helicopter force using cover and concealment will normally be able to occupy their BP and begin an engagement undetected. It is unlikely that ADA weapons and attacking aircraft will engage the attack helicopters at the same time, and air to air engagements are the least likely to occur.

a. Air to Surface

Air to surface attrition is caused by the attack helicopter unit firing on ground targets. It occurs once per engagement cycle and follows a two step process where (1) the total number of detected ground vehicles are determined and (2) ground vehicle losses are assessed. The process continues until all the ATKHB point fire missiles are expended or the mission abort criteria is reached.

The total number of ground vehicles detected is determined using binomial draws for each vehicle type v and the probability that line of sight exists between the helicopters in battle positions and the vehicles for the given terrain type t. Therefore, each trial size varies depending on the vehicle type but the probability of line of sight, $PLOS_t$, is the same for each trial.

$$Let\ X_v = number\ of\ vehicles\ type\ v\ detected,$$

$$then\ \ X_v \sim Binomial\ (\ n = n_v,\ p = PLOS_t)\ \ for\ all\ vehicles\ \ v = \{1,\ 2,\ \ldots\ ,\ V\}$$

The detected vehicles are then rank ordered by vehicle priority in accordance with user defined priorities based on the attack helicopter unit and the specific mission type.

EXAMPLE 3.6: Air to Surface Attrition Adjudication. Given opposing forces as described in Chapter I (an ATKHB with 10 AH-64's each with 16 Hellfire missiles attacking a ground force with 130 T80 tanks, 2 ZSU's, 2 SA-13's, 2 SA-6's, and 14 BMP's), determine the ground force attrition for the first engagement cycle. It is assumed that all aircraft made it to the objective area. The objective area is located in terrain that is rolling with an estimated PLOS = 0.55 for the BP range to target (6.5 km). The vehicle priority is (1) ADA, (2) tank, and (3) mechanized forces.

STEP 1: Determine number of enemy vehicles detected by the ATKHB and corresponding vehicle rank order.

Use binomial draws for each vehicle type:

SA-6	~ Bin(n=2, p=.55) = 1	rank order: A1
SA-13	~ Bin(n=2, p=.55) = 0	
ZSU	~ Bin(n=2, p=.55) = 1	A2
T80	~ Bin(n=130, p=.55) = 72	T1 - T72
BMP	~ Bin(n=14, p=.55) = 8	M1 - M8

The possible number of missiles, *Nmsls(k),* that can be fired at the rank ordered targets is determined based on the unmasked time for the current engagement cycle, the user defined average missile shot time, and the total number of aircraft for the current cycle, *A(k)*:

$$Nmsls\,(k) \;=\; \left(\frac{unmask\ time\ (k)}{avg\ shot\ time}\right) \times A(k) \tag{14}$$

where *Nmsls(k)* is rounded to the nearest integer value.

EXAMPLE 3.6 (a):

STEP 2: Determine total number of missiles fired.

Let *unmask time* ~ N(μ=15 sec, σ=3 sec) = 18 sec, assuming user defined mean and std dev parameters for the mission type.

Eqn (14) $Nmsls = \left(\frac{18\ sec}{avg\ shot\ time\ =\ 8\ sec}\right) \times 10\ aircraft = 22.5$ $\quad\therefore$ 23 missiles

---

The ground vehicle attrition is then calculated using either perfect fire distribution command and control (C2) or random fire distribution C2. Perfect C2 insures that each missile is fired at a different target. Random C2 allows for the possibility of more than one missile being fired at the same target, and is generally more realistic.

Attrition is assessed for each vehicle type v for every engagement cycle.

Let $N_v(k)$ be the number of vehicles type v at the start of cycle k and

$NK_v(k)$ be the number of vehicles killed during cycle k,

then $N_v(k+1) = N_v(k) - NK_v(k)$

The number of missiles allocated to each vehicle type is less than or equal to the number of vehicles of the given type detected. For example, given the rank ordered targeted vehicles, if the first three are ADA weapons followed by ten tanks and only five missiles are to be fired, the first three missiles are allocated to fire at ADA weapons and the last two are allocated against the tanks. If perfect C2 is used, each missile is fired at a different target - each target is drawn from the target set in rank order with no replacement between draws. If random C2 is used, each missile is fired at a target drawn from the target set but the selected target is then replaced and is available for the next draw (sampling with replacement).

Losses are determined for each vehicle based on a Bernoulli trial given the PK value. The PK is computed using the standard form $PK = 1 - (1 - SSPK)^{Nshots}$ where the SSPK is the user defined value for the aircraft type a against the ground vehicle type v and the number of shots is dependent on the perfect or random C2 missile allocations. If perfect C2 is used the number of shots per vehicle will be equal to one in every case. The number of shots can be greater than one only when random C2 is used.

EXAMPLE 3.6 (b):

STEP 3: Allocate each missile to a targeted vehicle based on the prioritized rank ordered targets. Perfect and Random C2 allocations are shown.

Perfect C2: 1-A1 2-A2 3-T1 4-T2 5-T3 6-T4 7-T5 thru 23-T21

Random C2: 1-A2 2-A2 3-T6 4-T22 5-T7 6-T18 7 thru 23 - random T(i) for i = 1, 2, 3, ..., 72 selected tanks.

Note: The number of missiles allocated each vehicle type does not exceed the number of vehicles of that type. In this example only two ADA vehicles were detected, therefore, only two missiles are allocated against ADA vehicles. Otherwise, the missiles are allocated by vehicle priority. Note also, that the labels are arbitrary and serve only to identify targets engaged with more than one missile.

STEP 4: Assess the ground force vehicle losses based on SSPK values for engagements between AH-64's and the given ground vehicle type at a range of 6.5 km and the number of missiles fired at the given target. *Random C2* attrition is the only method shown in this example. Each vehicle is attrited based on a Bernoulli trial: let X~U(0,1), if X≤ PK for the engagement then the vehicle is killed. Recall, if using Random C2 there may be more than one missile fired at the target and then the PK no longer equals the SSPK. The SSPK values are all fixed at .85 for this example.

Target	A2:	2 msls fired	(PK=.9775) and	X~U(0,1)=.5467	∴ A2 killed
	T6:	1 msl fired	(PK=.85) and	X~U(0,1)=.8971	∴ T6 survives
	T22:	1 msl fired	(PK=.85) and	X~U(0,1)=.3215	∴ T22 killed
	etc....				

STEP 5: Subtract losses from ground force to determine strength at start of next cycle.

SA-6(k+1)	= 2 - 0 = 2	
SA-13(k+1)	= 2 - 0 = 2	
ZSU(k+1)	= 2 - 1 = 1	(A2 killed)
T80(k+1)	= 130 - 18 = 112	(18 tanks killed of 21 that were fired at)
BMP(k+1)	= 14 - 0 = 14	(no BMPs were fired at)

The missile count is updated each cycle and cycles continue until all missiles are expended or the mission abort criteria is reached.

Let M(k) be the number of missiles remaining at the start of cycle k and

MF(k) be the number of missiles fired in cycle k,

then $M(k+1) = M(k) - MF(k)$

b. Surface to Air

Surface to air attrition takes place every engagement cycle k following air to surface adjudication if the ATKHB is in a BP within the lethal range of an ADA system. If more than one ADA system is within range, it is assumed all ADA systems within range are netted; all communicate to insure perfect command and control. Assuming perfect C2, the ADA system that has the shortest range is used to fire at the observed aircraft. The longer range ADA systems are usually reserved for use against the fixed wing aviation threat.

The adjudication steps as outlined for en route surface to air attrition in Section 2.a. apply with the following modifications. The ADA lethal ranges are determined the same way following *Step 1* procedures and are used to determine if the flight is engaged.

If $R_{BP\text{-}TGT} \leq R_L(n)$ then the ADA system type n has the opportunity to fire at the attack helicopters type a. This is done for all N ADA systems.

The number of shots the ADA system can take is calculated using equation (8) with a few modifications. The possible number of aircraft observed is determined using a binomial draw given the total number of aircraft for the engagement cycle, $A(k)$, and the PLOS value for the given terrain type; $A(k)\ Obs \sim Binomial\left(n = A(k)\,, p = PLOS_t\right)$. The engagement time is equal to the engagement cycle unmask time; $TE = Unmask\ Time\ (k)$. Therefore, equation (8) is modified such that

$$Nshots = \min\{\,[\,(Weapon\ Rate\ of\ Fire) \times Unmask\ Time\ (k)\,]\,, Ntot\,\}\,.$$

The value for the number of aircraft observed for the given cycle, $A(k)Obs$, may seem to be a conservative estimate but is actually a fairly good approximation. The ADA weapon systems are normally placed to protect the rest of the ground vehicles from threat air attack and maximize their ability to observe the main threat air avenues of approach. The PLOS for a given ADA system against an air threat is probably higher than the average point to point PLOS for the given terrain type which is used in the calculation. Therefore, the

calculation for the number of observable attack helicopters is based on the total number of aircraft (rather than the unmasked aircraft) to compensate for the possible low PLOS value used. The estimate would in fact be too low if all the aircraft were unmasked at the same time, which is not likely to occur. Based on the different attack methods as discussed in Chapter II, Section D, the actual number of aircraft that are unmasked at a given time can vary greatly and is normally between one-third to two-thirds of the total force.

The attrition assessment is then determined the same way as described in *Step 4* for en route surface to air attrition.

c. *Air to Air*

Air to air attrition adjudication is conducted the same way en route air to air attrition is handled. The air to air attrition adjudication follows the surface to air and air to surface attrition adjudication for the engagement cycle taking place when the attacking flight arrives.

E. THE MISSION CYCLE

The mission cycle refers to the mission readiness capabilities of the unit. As discussed in Chapter II, each attack helicopter unit has a specific mission planning and execution cycle to maximize mission support ability. Some units operate primarily at night while others operate during the day. The mission planning cycle defines these day and night blocks and is simplified by dividing the day into two 12 hour blocks, one for day and the other for night. This is consistent with the default air mission cycles that are used for fixed-wing aircraft in the current version of *JWAEP* (Youngren and Lovell, 1996).

The unit planning cycle is a user defined parameter that works in conjunction with the user defined unit day and night mission values. A unit that can execute one day mission and two night missions, for example, will be limited to three missions for the 24 hour period. The missions are scheduled every 12 hours in accordance with the planning cycle. Units are allowed to exceed day and night mission parameters but only with penalty. The maximum number of missions executed can not exceed two times the user defined number (*2* x *day or*

night msn #) and only for critical missions based on target priority. If the mission numbers are exceeded then the unit must remain inactive (no missions assigned) for the next planning cycle.

The mission cycle and number of day and night missions can be changed but again, following a change, the unit remains inactive for the next cycle. The inactive periods are used to represent the minimum time it takes a unit to adjust to a new mission cycle.

F. COMBAT SERVICE SUPPORT

The major classes of supply that are explicitly tracked for the unit's attack aircraft and are Classes III and V, aircraft fuel and ammunition. The unit *base.dat* file establishes the basic loads of each class for the specified re-supply cycle. For example, 12,500 gal of JP-4, 384 Hellfire, 1,824 70mm Rkts, and 28,800 30mm as depicted in the *ViperBase.dat* file. Those values also indicate the unit's fuel and ammunition capacity based on organic and additional OPCON assets that are normally task organized with the attack helicopter unit.

The mission logistics requirements are calculated for every mission once the flight route and the mission force size are determined. The logistics calculation serves three purposes: it decrements the current supply levels, provides a point estimate for future mission logistics requirements, and serves as a check to see if the mission is logistically feasible.

The fuel expended is based on the number of aircraft for the mission, the aircraft fuel burn rate, the distance to the target, and an added fixed time of 30 minutes to account for BP time, run-up time, and mission reserve requirements.

$$\boldsymbol{fuel\ used} = n\ aircraft \times \left[\left(\frac{2 \times flt\ path\ dist}{avg\ msn\ speed} \right) + 0.5\ hrs \right] \times fuel\ burn\ rate \qquad (15)$$

The ingress and egress flight path distances may vary but are assumed to be close enough to simply double the ingress route distance.

The number of expended rounds of ammunition is calculated based on the number of aircraft for the mission and the weapons load configuration. It is assumed that all aircraft expend all ammunition.

$$ammo_i\,used \;=\; (n\;aircraft) \times (ammo_i\,loaded) \qquad \forall\, i\; type\; ammo \tag{16}$$

EXAMPLE 3.7: Calculating Logistical Requirements. The ATKHB is conducting an attack using 10 AH-64 attack helicopters each with a heavy weapons load (16 Hellfire and 1500 30mm). The selected flight path distance is 120km from base to objective area.

STEP 1: Determine fuel required.

Eqn (15) $\quad fuel \;=\; 10 \times \left[\left(\dfrac{2 \times 120\,km}{avg\;msn\;speed = 200\,kmph}\right) + 0.5\,hrs\right] \times (fuel\;burn\;rate = 142\,gph) \;=\; 2414\,gals$

STEP 2: Determine ammunition required.

Eqn (16) $\quad Hellfire \;=\; 10 \times 16 = 160\,missiles$ $\quad$ and $\quad 30mm = 10 \times 1500 = 15000\,rounds$

G. MISSION TARGETING

The entire process of selecting targets and then assigning those targets to appropriate forces is an area that is beyond the scope of this thesis but merits some discussion. The assumption that attack helicopter missions are generated based on the assignment of targets to attack helicopter units is an important foundation to this thesis work. Therefore, there are several concepts that are relevant and should be included in the development of an attack mission generation module that follows simple, logical steps in the assignment of any target.

Target selection should be based on the principle of determining the opposing forces "critical" units and then targeting them based on a user defined priority. A "critical" unit could be defined as a unit that potentially could have the greatest impact on current and/or future operations. One way to select targets would be based on a target list data file that would list the expected types of opposing forces and the relative importance a commander would place on them based on the type of mission being conducted. For example, if a *Blue* armored division is conducting an attack against a defending *Red* mechanized corps, an important target would be any *Red* reserve armored force of battalion size or greater. If such a force is detected based on battlefield perception, it would be targeted with a high priority.

The *deep* target, not currently engaged by other ground forces, that is assigned to the attack helicopter unit must be selected using a logical algorithm that considers several factors. The target selection algorithm should incorporate the type of target and its priority, the major ground force responsible for the target area, and deep attack assets available. The type of target and available assets is important because certain targets are better suited for specific available weapons. Deep strike weapons include attack helicopters as well as long range artillery and fixed wing aircraft. Therefore, an attack helicopter mission should be generated for an ATKHB if it is the best asset for the target or if it is the only asset that can hit the target.

A method of associating a major ground unit with an operational area (an area within which the major unit can directly influence with combat forces - the rear, close, and deep battle areas) would enhance the ability to assign targets to appropriate units and weapon systems. The most straight forward way to associate targets with major ground forces is based on the ground unit's sphere of influence. The *sphere of influence* for a given unit can be defined as the area within which the unit can directly impact combat operations. A division, for example, may be able to influence the battlefield up to 12 hours out or 120 km assuming a ground movement speed of 10 km per hour and a corps may be able to influence the battlefield up to 24 to 72 hours out. The areas would be based on available organic weapon systems, the terrain, and commanders intent.

As targets are selected and prioritized in the given unit areas, they would be assigned to subordinate organic forces. If the unit does not have the appropriate force or weapon system for a selected target, the target would be assigned to the unit's parent unit. For example, if a division is assigned an attack helicopter battalion target but its only attack battalion has been destroyed, the mission would then be assigned to the division's parent corps.

H. MODELING "RED" ATTACK HELICOPTER FORCES

The modeling of attack helicopter operations for forces that are different from U.S. forces can also be handled using the same logic that has been described in this thesis or

currently exists in the *JWAEP Version 2.0* Simulation. The two methods that can be used depend on the way in which the attack helicopter forces are doctrinally employed. If they are employed in a way that resembles U.S. attack helicopter operations, then the module described in this thesis can be used. The alternative is to use the existing JWAEP air war logic if their employment more closely resembles *Air Force* type employment - individual aircraft assigned to sortie packages for specific missions.

The unique data files associated with every attack helicopter unit make it possible to represent different forces (forces that may be organized differently and use different employment techniques). The files as described in Section A contain the information that makes that unit unique. The *aircraft.dat* file is obviously unique but the real power to change the way in which the Red ATKHB operates is by changing the parameters in the *unit.dat* and *mission type.dat* files.

The current version of the JWAEP Simulation describes how attack helicopter forces can be represented in the air war module in the close air support or strike role (Youngren and Lovell, 1996). There are some limitations in portraying helicopter operations using the air war module but these are probably insignificant if the attack helicopters are employed like attack fixed wing aircraft.

IV. MODEL DEMONSTRATION

This chapter demonstrates the network flight path selection algorithm and objective area attrition. The purpose is to demonstrate face validity by showing the results obtained using the methodology outlined in Chapter III given typical test scenarios. The intent is to better familiarize the reader with these two specific modeling areas and to show the variability gained by using the stochastic techniques previously described.

A. FLIGHT PATH GENERATION

The network "shortest path" algorithm used to define the optimal flight path is demonstrated using a 24-node network. The network is a portion of the 64-node network that was developed to represent the mobility corridors of the Korea Major Regional Contingency (MRC) in Karl M. Schmidt's Master's Thesis, *Design Methodology for FTLM*, 1993. The 24-node network is depicted in Figure 4.1. A detailed arc and node index with associated distances and threat levels can be found in Appendix B.

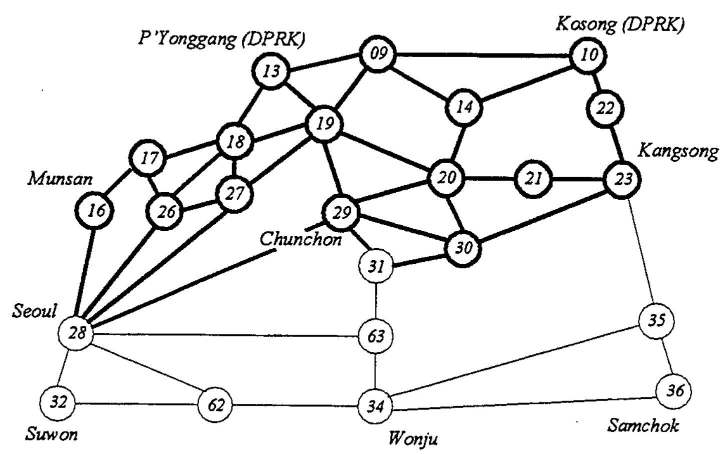

Figure 4.1 *24-Node Network.* The depicted network is a portion of the 64-node network developed for the Korea MRC [Schmidt, 1993]. The arcs and nodes that are highlighted in bold have (randomly assigned) threat levels that are fixed for flight path demonstration purposes. The network as depicted is not drawn to scale.

Flight paths were generated for four different test cases using three different weighting methods each. All cases used node 34 (Wonju) as the starting node S. The threat levels for the arcs and nodes north of nodes 23, 28, 30, and 31 were assigned randomly and remained fixed for each case.

1. Test Cases

The four test cases are outlined in Table 4.1 and are defined by the start node S, and the target node T. Three flight paths were selected for each test case based on a different weighting scheme. Recall the calculation for the (i,j) flight path segment for risk is: $r_{ij} = w_d(d_{ij}/R) + w_t t_{ij}$. The three weighting schemes varied to place the priority on (1) the distance with $w_d = 1$, (2) the threat level with $w_t = 1$, and (3) equal between the threat and the distance with $w_d = 0.5$ and $w_t = 0.5$.

Case	*Start Node*	*Target Node*
1	34 - Wonju	16 - Munsan
2	34 - Wonju	13 - P'Yonggang (DPRK)
3	34 - Wonju	10 - Kosong (DPRK)
4	34 - Wonju	23 - Kansong

Table 4.1 *Flight Path Test Cases.*

2. Test Results

The results for all twelve flight paths are shown in Table 4.2 and include the total distance and threat for the path chosen. The results show how potentially sensitive the selected flight path may be to the weight assigned to the threat level. Case 3 provides an example. The target node for Case 3 is just within the combat range (250 km) of the aircraft and a flight path is only selected when the weight for distance is equal to one; the path is based only on the distance. When the flight path is selected based on risk only, the target

node is no longer within range. The test results indicate that the weight should favor distance over threat level for targets at ranges close to the combat range of the aircraft. The results also indicate that a lower bound should probably be placed on the distance weight, w_d, to insure the path selected is never based solely on threat levels.

Case	*Priority*	*Selected Flight Path*	*Total Distance* $\sum_{(i,j)\in Flt\,Path} d_{ij}$	*Total Threat* $\sum_{(i,j)\in Flt\,Path} t_{ij}$
1	distance	34→63→28→16	185 km	.09
	threat	34→63→28→16	185 km	.09
	even	34→63→28→16	185 km	.09
2	distance	34→63→31→29→19→13	206 km	2.55
	threat	34→63→28→26→18→13	250 km	2.26
	even	34→63→31→29→19→13	206 km	2.55
3	distance	34→63→31→30→23→22→10	234 km	2.85
	threat	tgt not within range based on risk adjusted flt path	n/a	n/a
	even	tgt not within range based on risk adjusted flt path	n/a	n/a
4	distance	34→63→30→23	186 km	1.31
	threat	34→35→23	220 km	0
	even	34→35→23	220 km	0

Table 4.2 *Network Flight Path Test Results.*

The network flight path trees associated with each weighting method are illustrated in Figures 4.2, 4.3, and 4.4.

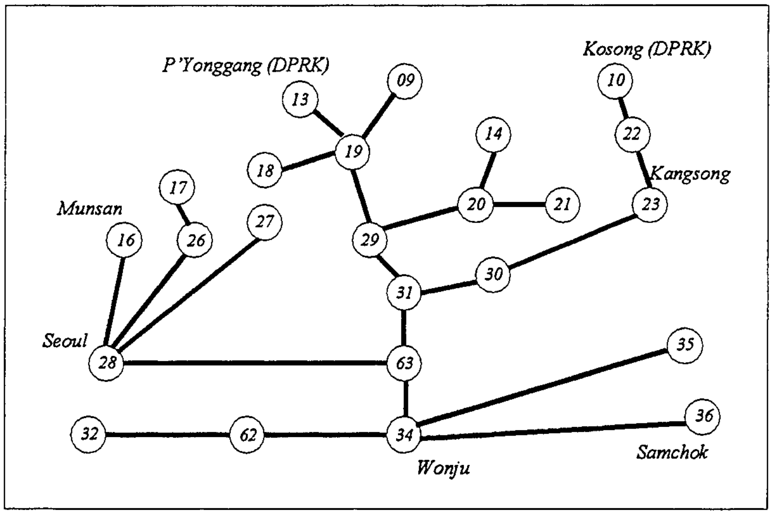

Figure 4.2 *Flight Path Tree (Priority to Distance).*

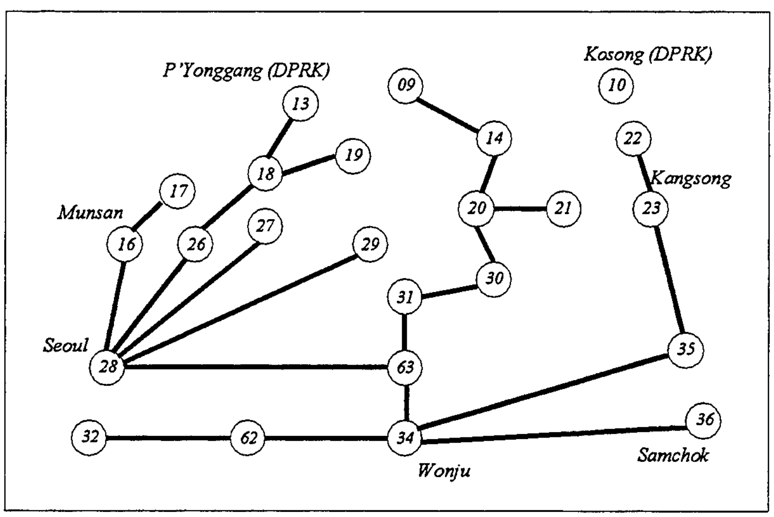

Figure 4.3 *Flight Path Tree (Priority to Threat).*

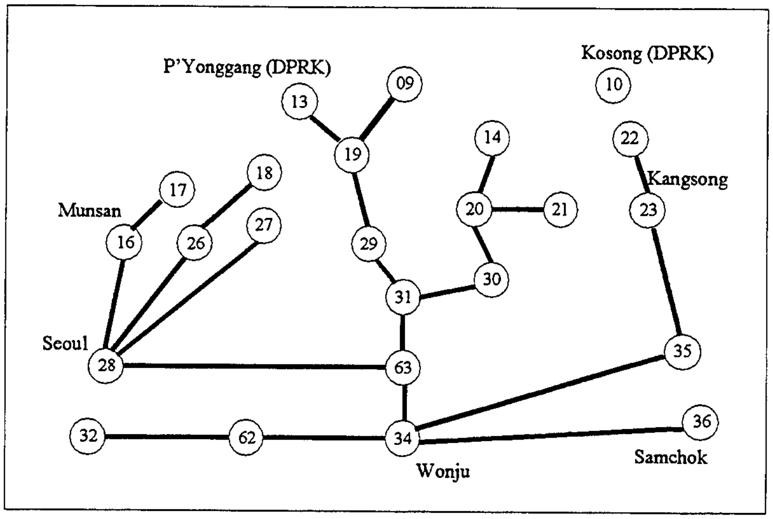

Figure 4.4 *Flight Path Tree (Equal Priority).*

B. OBJECTIVE AREA ATTRITION

The objective area attrition was demonstrated using a spreadsheet simulation to represent the attrition interaction between forces as outlined in the scenario described in Chapter I. The starting force strengths, BP to target range, PLOS value, and the SSPK values remained fixed for each of the ten replications that were run. The effects of en route attrition were not considered for the purposes of this demonstration.

1. Test Scenario

The simulations were set up with an AH-64 ATKHB attacking an Independent Tank Regiment (ITR). The starting force strength for the *Blue Force* was 10 AH-64's based on the required number of aircraft to destroy 70% of the ITR total force (105 of 150 combat vehicles). The Red Force starting strength was the same as outlined in Table 1.2, Chapter I. The *Red Force* (Listed by ATKHB attack priority) included 2 SA-6 ADA , 2 SA-13 ADA, 2 ZSU ADA, 130 T-80 tanks, and 14 BMP's. The mission abort criteria for the ATKHB was set at five aircraft; if five or more aircraft were destroyed, the ATKHB aborted the mission and broke off the engagement.

The objective area node used for the test replications was Munsan (node 16 from the 24-Node Network) with a PLOS equal to 0.38 . The PLOS value used is based on the Department of the Army *Intervisibility Classification Study,* TRAC-WSMR-TR-23-86, Volume 1, October 1986, Table 6-5, page 6-14. The BP to target range was set at 4 km which is a realistic distance for the type of aircraft used.

One of the test cases in which three engagement cycles were completed is shown below to illustrate the types of values associated with each engagement cycle and how they changed as the respective forces were attrited. Note the differences achieved between the use of Perfect C2 and Random C2.

Engagement Cycle 1 unmask time: 21.6 seconds Tot ATKHB Shots: 27 missiles

Command and Control	Perfect C2					Random C2				
vehicle type	SA-6	SA-13	ZSU	T-80	BMP	SA-6	SA-13	ZSU	T-80	BMP
begin strength = $N_t(1)$	2	2	2	130	14	2	2	2	130	14
# observed ~ Bin($N_t(1)$, PLOS)	2	0	0	48	2	2	0	0	48	2
total missile allocation	2	0	0	25	0	2	0	0	25	0
# vehicles fired at	2	0	0	25	0	2	0	0	20	0
# vehicles killed	2	0	0	21	0	2	0	0	19	0
end strength = $N_t(2)$	0	2	2	109	14	0	2	2	111	14

	AH-64
begin strength = A(1)	10
# observed ~ Bin(A(1), PLOS)	1
total ADA missile allocation	3
# A/C fired at	1
# A/C killed	1
end strength = A(2)	9

Engagement Cycle 2 unmask time: 22.22 seconds Tot ATKHB Shots: 25 missiles

Command and Control	Perfect C2					Random C2				
vehicle type	SA-6	SA-13	ZSU	T-80	BMP	SA-6	SA-13	ZSU	T-80	BMP
begin strength = $N_t(2)$	0	2	2	109	14	0	2	2	111	14
# observed ~ Bin($N_t(2)$, PLOS)	0	0	2	52	6	0	0	2	51	6
total missile allocation	0	0	2	23	0	0	0	2	23	0
# vehicles fired at	0	0	2	23	0	0	0	1	20	0
# vehicles killed	0	0	2	21	0	0	0	1	18	0
end strength = $N_t(3)$	0	2	0	88	14	0	2	1	93	14

	AH-64
begin strength = A(2)	9
# observed ~ Bin(A(2), PLOS)	3
total ADA missile allocation	3
# A/C fired at	3
# A/C killed	2
end strength = A(3)	7

Engagement Cycle 3 unmask time: 8.34 seconds Tot ATKHB Shots: 7 missiles

Command and Control	Perfect C2					Random C2				
vehicle type	SA-6	SA-13	ZSU	T-80	BMP	SA-6	SA-13	ZSU	T-80	BMP
begin strength = $N_t(3)$	0	2	0	88	14	0	2	0	93	14
# observed ~ Bin($N_t(2)$, PLOS)	0	1	0	38	6	0	1	0	30	6
total missile allocation	0	1	0	6	0	0	1	0	6	0
# vehicles fired at	0	1	0	6	0	0	1	0	5	0
# vehicles killed	0	1	0	4	0	0	1	0	4	0
end strength = $N_t(3)$	0	1	0	84	14	0	1	0	89	14

	AH-64
begin strength = A(3)	7
# observed ~ Bin(A(3), PLOS)	2
total ADA missile allocation	3
# A/C fired at	2
# A/C killed	2
end strength = A(4)	5

* Mission abort criteria met → engagement ends and remaining A/C return to base.

	Blue A/C Losses		Red Losses Perfect C2		Red Losses Random C2	
Final Outcome:	5	50%	51	34%	46	31%

2. Test Results

The objective area attrition results obtained from 10 test replications of the scenario described are summarized in Table 4.3. It is interesting to note that in eight of ten replications, the ATKHB broke off the attack because the abort criteria was met. Given the ADA threat encountered, that is reasonable. An ATKHB conducting a mission as portrayed in the scenario would have additional support like electronic warfare assets and artillery to help suppress enemy air defenses. No additional mission support assets were included in this simulation so the test results obtained make sense.

Replication	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*8*	*10*
Eng Cycles	4	3	2	11	3	2	3	13	3	4
Msn Abort	yes	yes	yes	no	yes	yes	yes	no	yes	yes
Aircraft Killed	6	5	6	1	5	6	7	4	5	5
Perfect C2										
Red Killed	55	51	24	137	53	31	51	136	44	45
% Red Killed	37%	34%	16%	91%	36%	21%	34%	91%	29%	30%
Random C2										
Red Killed	50	46	19	115	39	21	32	117	30	39
% Red Killed	33%	31%	13%	77%	26%	14%	21%	78%	20%	26%

***Table 4.3** Objective Area Attrition Results.*

The results also showed that in the cases when the ATKHB expended all missiles, the enemy ground force was attrited as expected. The mission force size was determined based on the number of aircraft required to destroy 70% of the ground force so the simulation should have shown at least 70% attrition as it did. Another result that was expected was the difference in attrition between perfect and random command and control. The number of vehicles killed using perfect C2 was higher than the number killed using random C2, however, in many cases it was not significant.

V. CONCLUSION

A. SUMMARY

This thesis describes some basic modeling formulations that can be used to represent attack helicopter operations in theater level simulations. The attack helicopter module describes the major events that take place in deliberate attack helicopter operations and the formulations that can be used to represent them. The goal was the development of simple, straight forward stochastic models to support the realistic portrayal of attack helicopter operations.

Although the emphasis of the thesis was the representation of attack helicopters conducting deliberate attacks, many of the areas discussed have applications that can be used to represent any helicopter operation. Many of the formulations are general in scope and simple enough to be modified to represent other types of helicopter forces and different missions. An effort was also made to represent helicopter forces in the same way that ground maneuver forces are represented. Many low resolution simulations fail to model helicopter forces or model them in the same way that fixed wing aircraft are represented.

The attack helicopter module has been developed to be incorporated into the *Joint Warfare Analysis Experimental Prototype* (JWAEP) but can easily be used in any theater level model. It should be pointed out, however, the formulations and module logic have not yet been validated. Face validity has been shown with examples and demonstration results discussed in Chapter IV but further testing is required. Additional simulation should be used to obtain module output which in turn can be compared with results from high resolution models, exercises (e.g., National Training Center data), and possibly some historical data that more accurately characterize attack helicopter operations. The attack helicopter module cannot be verified until it has been coded and tested in the actual JWAEP simulation.

B. TOPICS FOR FURTHER STUDY

1. Targeting

A module needs to be developed that addresses the issues of how to identify, prioritize, and assign targets. The targeting process is complicated and is often not represented well in combat simulations. A simple module that identifies and then follows a logical algorithm to prioritize and assign targets to major units (division and higher) should be explored. The unit or weapon system within the major command that is most suitable for the mission can then be assigned the given target.

2. Line of Sight Probabilities

The probability that an observer from a given location has line of sight to a target location is an important concept in combat simulations. The problem that needs to be addressed in JWAEP is how to implicitly model the impact of line of sight, or more importantly the obstruction of line of sight has on helicopter operations. Therefore, a more thorough study of line of sight is required. PLOS distribution curves or look up tables are needed to support the air to ground line of sight interactions associated with low altitude helicopter operations.

The probability that line of sight exists between helicopters and ground forces is different than the typical PLOS used to characterize ground engagements which is normally used in simulations. First, the vantage points are different. Helicopters typically operate at altitudes from 10 to 200 feet above ground level which can have a significant impact on line of sight probabilities depending on the type of terrain. The other not so obvious difference is the tactical employment of forces to maximize line of sight capabilities. Attack helicopters normally occupy battle positions that have the best line of sight vantage points for a given engagement area. Conversely, ground based ADA systems are employed to cover the most likely air avenues of approach and also seek the best line of sight vantage points to target threat aircraft.

3. Attack Module Complexity

This thesis represents the initial research in the formulation of models to represent the portrayal of helicopter operations in JWAEP. The modeling formulations in this thesis are fairly simple and several areas should be enhanced to make the module more robust.

One area worthy of attention is attrition. All the attrition models can be made more complex to allow for more force interactions. For example, enhancements to allow ground forces to engage helicopters with small arms fire. The effect small arms fire has on attack helicopters in the conduct of a mission may be negligible but that type of fire can have significant effects on other helicopter forces. The formulations which support the deliberate attack mission do not include attrition due to area fire weapons like the 70mm rocket or short range weapons like the 30mm cannon. They may have significant effects on attrition for other missions like reconnaissance and should be incorporated.

Another area is fire distribution command and control. Two options, perfect C2 and random C2, were used in the formulations presented but neither are totally representative of the way in which fire distribution is handled. The effects of battlefield awareness in the context of information warfare and digital communications technology on command and control should be incorporated into the module.

The attack module described does not address the use of additional assets for suppression of enemy air defenses. Enhancements to incorporate lethal and nonlethal suppression of enemy air defenses should be investigated to make the attack missions more realistic.

Finally, the types of missions attack helicopter units can perform needs to be expanded. The deliberate attack is the only mission discussed in this thesis. The development of modules to support other attack helicopter missions to include armed reconnaissance, air assault escort, and air combat should be accomplished. This type of research would also lead to the development of modules to support different types of helicopters in the conduct of a myriad of missions.

APPENDIX A. NETWORK SHORTEST PATH ALGORITHM

- Algorithm Input:

G = (N, A) {the network in linked node, forward star (FS) arc adjacency list}
S {the starting node}
T {the ending node}
R {combat range of the attack helicopter unit - ½ of the total mission range}
d_{ij} {distance from node *i* to node *j* in kilometers}
w_d {weight or relative importance of distance}
w_t {weight or relative importance of threat where ($w_d + w_t = 1.0$) }
t_{ij} {perceived ADA threat level from node *i* to *j* on a scale of 0 to 1, 1 being the highest threat}

- Variables:

$TD(i) = \sum_{(i,j) \in Pred\ List} d_{ij}$ {total distance at node *i* based on the optimal path from the predecessor list}

$TR(i) = \sum_{(i,j) \in Pred\ List} r_{ij}$ {total risk at node *i* based on the optimal path}

$r_{ij} = w_d \left(\frac{d_{ij}}{R} \right) + w_t t_{ij}$ {arc (*i,j*) cost}

Note: The calculation for cost is based on weighted values for arc distance and threat level. The distance is normalized for combat range *R* to give it the same relative order of magnitude (0 to 1) as the threat level.

- Output:

MinPath {the path from the predecessor list}
Dist {total dist from *S* to *T* based on optimal path}
Total Risk {total ADA risk from *S* to *T* based on optimal path}

```
begin
    TD(S) = 0;
    TD(j) = ∞; for all j ∈ N-S
    TR(S) = 0;
    TR(j) = ∞; for all j ∈ N-S
    R = Combat Range
    LIST ← S; {assumed to be a FIFO queue}
    while LIST ≠ nil do
```

```
        begin
            remove element i from LIST;
            for each arc (i, j) ∈ FS(i) do
            begin
                if TD(i) + d_ij ≤ R then
                begin
                    if TR(j) > TR(i) + r_ij then
                        begin
                        TR(j) = TR(i) + r_ij;
                        TD(j) = TD(i) + d_ij;
                        pred(j) ← i ;
                        if j ∉ LIST then add j to LIST;
                    end if;
                end if;
            end for,
        end while;
        if TD(t) < ∞ then {t is within range; TD(t) = ∞ if node t is not within range R}
        begin
            build path_st from pred list corresponding to min risk path;
            Output: MinPath = path_st , Dist = TD(t), and Total Risk = TR(t);
        else
            MinPath does not exist - the destination node t is not within range;
        end if;
    end.
```

APPENDIX B. ARC AND NODE INDEX FOR THE 24-NODE NETWORK

The 24-node network below is a portion of the 64-node network developed to represent the Korea Major Regional Contingency (Schmidt, 1993). The risk values associated with each arc were calculated using formulas in Chapter III to support the demonstration as described in Chapter IV. Arcs are represented as node pairs (i - j). The arcs that are shown as (i - i') represent split nodes that have associated areas.

Network Incident Node Listing

node	incident nodes
9	10, 13, 14, 19
10	9, 14, 22
13	9, 18, 19
14	9, 10, 20
16	17,28
17	16, 18, 26
18	13, 17, 19, 26, 27
19	9, 13, 18, 20,
20	14, 19, 21, 29, 30
21	20, 23
22	10, 23
23	21, 22, 30, 35
26	17, 18, 27, 28
27	18, 19, 26, 28
28	16, 26, 27, 29, 32, 62, 63
29	19, 20, 28, 30, 31
30	20, 23, 29, 31
31	29, 30, 63
32	28, 62
34	35, 36, 62
35	23, 34, 36
36	34, 35
62	28, 32, 34
63	28, 31, 34

Arc	Dist (km)	risk 1 Priority to Dist	risk 2 Priority to Threat	risk 3 No Priority
9 - 9'	10	0.04	0.03	0.0339
9 - 10	80	0.32	0.74	0.5294
9 - 13	50	0.20	0.62	0.4121
9 - 14	40	0.16	0.72	0.4415
9 - 19	40	0.16	0.99	0.5770
10 - 10'	10	0.04	0.18	0.1091
10 - 14	50	0.20	0.73	0.4669
10 - 22	30	0.12	0.15	0.1336
13 - 13'	12	0.05	0.46	0.2551
13 - 18	15	0.06	0.75	0.4035
13 - 19	20	0.08	0.72	0.4003
14 - 14'	10	0.04	0.37	0.2041
14 - 20	20	0.08	0.20	0.1407
16 - 16'	10	0.04	0.02	0.0297
16 - 17	30	0.12	0.30	0.2092
16 - 28	40	0.16	0.09	0.1238
17 - 17'	10	0.04	0.58	0.3107
17 - 18	30	0.12	0.12	0.1189
17 - 26	15	0.06	0.66	0.3624
18 - 18'	10	0.04	0.85	0.4442
18 - 19	15	0.06	0.16	0.1099
18 - 26	20	0.08	0.16	0.1218
18 - 27	20	0.08	0.61	0.3462
19 - 19'	16	0.06	0.25	0.1550
19 - 20	40	0.16	0.23	0.1932
19 - 27	30	0.12	0.53	0.3238
19 - 29	45	0.18	0.04	0.1100
20 - 20'	20	0.08	0.69	0.3833
20 - 21	25	0.10	0.31	0.2065
20 - 29	30	0.12	0.20	0.1601
20 - 30	30	0.12	0.92	0.5176
21 - 21'	16	0.06	0.39	0.2254
21 - 23	30	0.12	0.86	0.4904
22 - 22'	8	0.03	0.65	0.3431
22 - 23	20	0.08	0.74	0.4093

Arc	*Dist (km)*	*risk 1* *Priority to Dist*	*risk 2* *Priority to Threat*	*risk 3* *No Priority*
23 - 23'	10	0.04	0.02	0.0311
23 - 30	50	0.20	0.72	0.4588
23 - 35	90	0.36	0.59	0.4749
26 - 26'	10	0.04	0.49	0.2668
26 - 27	25	0.10	0.84	0.4677
26 - 28	50	0.20	0.01	0.1063
27 - 27'	10	0.04	0.77	0.4040
27 - 28	50	0.20	0.85	0.5263
28 - 28'	30	0.12	0.00	0.0600
28 - 29	80	0.32	0.11	0.2143
28 - 32	30	0.12	0.00	0.0600
28 - 62	55	0.22	0.00	0.1100
28 - 63	70	0.28	0.00	0.1400
29 - 29'	10	0.04	1.00	0.5200
29 - 30	25	0.10	0.45	0.2731
29 - 31	35	0.14	0.54	0.3411
30 - 30'	16	0.06	0.16	0.1096
30 - 31	30	0.12	0.41	0.2640
31 - 31'	10	0.04	0.44	0.2393
31 - 63	25	0.10	0.00	0.0500
32 - 32'	10	0.04	0.00	0.0200
32 - 62	50	0.20	0.00	0.1000
34 - 34'	10	0.04	0.00	0.0200
34 - 35	110	0.44	0.00	0.2200
34 - 36	110	0.44	0.00	0.2200
34 - 62	50	0.20	0.00	0.1000
34 - 63	25	0.10	0.00	0.0500
35 - 35'	10	0.04	0.00	0.0200
35 - 36	50	0.20	0.00	0.1000
36 - 36'	14	0.06	0.00	0.0280
62 - 62'	10	0.04	0.00	0.0200
63 - 63'	10	0.04	0.00	0.0200

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